A MIXING ZONE GUIDANCE DOCUMENT PREPARED FOR THE OREGON DEPARTMENT OF ENVIRONMENTAL QUALITY

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Introduction

In the United States, point source discharges to navigable waters are regulated through National Pollutant Discharge Elimination System (NPDES) permits as required under Federal law by means of the Clean Water Act (CWA). In the State of Oregon, these permits are administered by the Oregon Department of Environmental Quality. These permits are written to satisfy all state and federal water quality regulations.

The Clean Water Act allows for the use of mixing zones, also known as "allocated impact zones", as long as acute toxicity to drifting organisms is prevented and the integrity of the waterbody as a whole is not impaired. Mixing zones allow the initial mixing of waste and receiving water, but are not designed to allow for treatment. EPA does not have specific regulations pertaining to mixing zones. Each state must adopt its own mixing zone regulations which are subject to review and approval by EPA. In Ssates that lack approved mixing zone regulations, ambient water quality standards must be met at the end of the pipe.

With the increase in water quality issues, the long list of water quality limited streams, and endangered species listings in Oregon, writing NPDES permits is becoming more complicated and technically more challenging. The use of mixing zone studies is becoming more prevalent. The resulting data from mixing zone studies needs to be increasingly more thorough and expansive in scope. The scientific world is becoming more knowledgeable about the effects of pollutants on our environment. Mixing zone studies need to be more thorough and reflect the ever-increasing gains in scientific research and knowledge.

This document is intended to address some of these issues and to assist permittees, consultants, and Department staff on the information that is needed to adequately assess the application of mixing zones. The document also summarizes the state and federal regulations and policies relating to mixing zones, a background on hydrodynamic mixing processes (dilution theory), and a short discussion on mixing zone modeling.

The document is broken up into four chapters;

1. State and Federal rules and guidance
2. Mixing Zone Report
3. Hydrodynamic Mixing Process Theory
4. Mixing Zone Modeling

The first chapter provides a summary of the rules and guidance the Department of Environmental Quality (Department or DEQ) adheres to when applying mixing zones to point source discharges. The first section summarizes the Oregon Administrative Rules (OARs) pertaining to mixing zones. The next sections summarize EPA's rules and guidance on mixing zones. The Department relies heavily on the guidance documents, policies, and analytical tools provided by EPA for the application of mixing zones.

The second chapter summarizes the Department’s requirements of a mixing zone study. Often times the Department requires a source to perform a mixing zone study and the source is uncertain what is expected. The section should make clear the type of information the Department needs from a mixing zone study to adequately assess the impact of the discharge on water quality standards and beneficial uses.

Chapter three provides an introduction to the fundamental aspects of hydrodynamic mixing processes. Mixing is a complicated process. This chapter gives enough detail to provide permit writers, managers, and policy makers an adequate understanding of this subject. References cited should be consulted for further information.

The final chapter gives a brief overview of mixing zone modeling. This section discusses how to choose an appropriate mixing model for a given scenario, provides insight into sensitivity analysis, and provides a brief overview of some of the available models.

This document serves as a single tool to assist permit writers, managers, permittees, or consultants in understanding the Department's approach to mixing zone analysis. Included in the guidance document is a list of references that can act as other tools to assist the user in their mixing zone analysis. A fairly good working knowledge of mixing zones, water quality analysis, and DEQ and EPA rules and guidance is helpful to fully gain the benefits of this guidance document but not necessary.

This document was written so that each chapter can be read as a stand-alone document. The intention is to allow the reader the ability to read one chapter without having to have read previous chapters. A glossary of terms is contained at the end of the document so users can thumb quickly to it to find definitions of technical or other unfamiliar terms. Because each chapter is intended to be a stand-alone document, there will be some redundancy throughout the document.

The Department maintains guidance documents to assist permit writers. These guidance documents are updated and modified over time. The intention of this guidance document is that it will be edited and improved over the years. Comments and suggestions will be greatly appreciated from those who use this document.

Chapter 1

DEQ and EPA mixing zone regulations and guidance

> *It is not always necessary to meet all water quality criteria within the discharge pipe to protect the integrity of the water body as a whole. Sometimes it is appropriate to allow for ambient concentrations above the criteria in small areas near outfalls. These areas are called mixing zones. Whether to establish a mixing zone policy is a matter of State discretion, but any State policy allowing for mixing zones must be consistent with the Clean Water Act and is subject to approval of the Regional Administrator. (USEPA, August 1994)*

The concept of mixing zones as a regulatory tool to address the incomplete mixing of wastewater discharges in receiving waters has been embraced by both EPA and its predecessor agencies as part of a larger regulatory effort to ensure that point source discharges of wastes do not impair beneficial uses. EPA interprets the Clean Water Act (CWA) as allowing the use of mixing zones as long as the provisions addressing toxicity at section 101(a)(3) are met and the designated uses of the water body as a whole are protected. One court has considered the application of a mixing zone in a discharge permit and upheld EPA's use of a limited mixing zone (Hercules v. EPA, 598 F.2d 91 (D.C. Cir. 1978)) (EPA, 1998).

EPA's current policy addresses mixing zones as allocated impact zones (AIZs) where certain numeric water quality criteria may be exceeded as long as: there is no lethality to organisms passing through the mixing zone, there are no significant risks to human health, and the designated and existing uses of the water body are not impaired as a result. This includes protecting areas of feeding and breeding, and other critical habitat (e.g. shellfish growing areas, salmonid spawning and rearing, shoreline habitat, mouths of tributaries, and shallows)(EPA, 1998).

EPA's policy has always been to protect both nonmotile benthic and sessile organisms in the mixing zones as well as the protection of free-swimming and drifting organisms. However, States and Tribes have focussed primarily on the protection of free-swimming and drifting organisms (EPA, 1998). Limiting the size of the mixing zone is meant to protect swimming and drifting organisms while limiting the placement of mixing zones is meant to protect nonmotile organisms.

EPA stresses the importance of not abusing the use of mixing zones in the following statement:

> *Mixing zone allowances will increase the mass loadings of the pollutant to the water body and decrease treatment requirements. They adversely impact immobile species, such as benthic communities, in the immediate vicinity of the outfall. Because of these and other factors, mixing zones must be applied carefully, so as not to impede progress toward the Clean Water Act goals of maintaining and improving water quality (EPA, 1994).*

1.1 DEQ Rules

1.1.1 Rules for Standard Mixing Zones

Below is a summary of the key aspects of the Department's mixing zone rules. A complete copy of the rules are contained in appendix A.

Definition: The Department may allow a designated portion of a receiving water to serve as a zone of dilution for wastewaters and receiving waters to mix thoroughly and this zone will be defined as a **mixing zone**.

Mixing Zone Criteria
The Department may suspend all or part of the water quality standards, or set less restrictive standards, in the defined mixing zone, provided the following conditions are met:

The water within the mixing zone shall be free of:

1. Materials in concentrations that will cause acute toxicity to aquatic life as measured by a Department approved bioassay. Acute toxicity is defined in the rule as lethality to aquatic life as measure by a significant difference in lethal concentration between the control and 100 percent effluent in an acute bioassay test. Lethality in 100 percent effluent may be allowed due to ammonia and chlorine only when it is demonstrated on a case-by-case basis that immediate dilution of the effluent within the mixing zone reduces toxicity below lethal concentrations. The Department may on a case-by-case basis establish a zone of immediate dilution if appropriate for other parameters.

2. Materials the will settle to form objectionable deposits.

3. Floating debris, oil, scum, or other materials that cause nuisance conditions.

4. Substances in concentrations that produce deleterious amounts of fungal or bacterial growths.

The water outside the boundary of the mixing zone shall:

1. Be free of materials in concentrations that will cause chronic toxicity.

2. Meet all other water quality standards under normal annual low flow conditions.

In addition, the Department shall define a mixing zone in the immediate area of a wastewater discharge to:

1. Be as small as feasible.

2. Avoid overlap with other mixing zones and be less than the total stream width as necessary to allow passage of fish and other aquatic organisms.

3. Minimize adverse effects on the indigenous biological community especially when species are present that warrant special protection.

4. Not threaten public health. This statement in the Department's mixing zone rules is understood to mean that no mixing zone is allowed for bacteria. Bacteria criteria must be met at the end of the pipe.

5. Minimize adverse efffects on other designated beneficial uses outside the mixing zone.

Location
In determining the location, surface area, and volume of a mixing zone, the Department may use appropriate mixing zone guidance to assess the biological, physical, and chemical character of receiving waters, and effluent, and the most appropriate placement of the outfall, to protect instream water quality, public health, and other beneficial uses. EPA provides extensive guidance related to mixing zones in the Water Quality Standards Handbook (the Handbook) and the Technical Support Document (the TSD).

The Department may change mixing zone limits or require the relocation of an outfall if it determines that the water quality within the mixing zone adversely affects any existing beneficial uses in the receiving waters.

Request for Information
The Department may request specific information to assist in determining the appropriate size and location of a mixing zone or whether one should be granted at all. The information may include:

- Type of operation to be conducted

- Characteristics of effluent flow rates and composition
- Characteristics of low flows of receiving waters
- Description of potential environmental effects
- Proposed design for outfall structures.

The Department may also require mixing zone monitoring studies and/or bioassays to be conducted to evaluate water quality or biological status within and outside the mixing zone boundary.

1.1.2 Alternate Mixing Zones

In 1996, the Department made substantial changes to its mixing zone rules and added language describing alternate requirements for mixing zones. This new language was added to address existing or proposed discharges in which it was not practicable to treat the wastewater to a level in which water quality standards could be met within a short distance downstream. An alternate mixing zone may be approved by the Department if the applicant can demonstrate one or more of the following:

1. The discharge creates an overall environmental benefit
2. The discharge is to a constructed water course
3. The discharge is insignificant

Environmental Benefit
For the Department to grant an alternate mixing zone based on the assumption that the discharge creates an environmental benefit, the source must demonstrate the following:

- All practical strategies have been or will be implemented to minimize the pollutant loads in the effluent.

- For proposed increased discharges, the current actual discharge and mixing zone does not meet the requirements of a standard mixing zone.

- Either an environmental benefit would be lost if the discharge did not occur, or the discharger mitigates the effects of the discharge that results in a net environmental benefit.

There is a list of nine items describing information the applicant must provide to demonstrate an environmental benefit will result from the discharge. The rules are presented in their entirety in appendix A.

Constructed Water Course
The Department may grant an alternate mixing zone if the discharge is to a constructed water course. The mixing zone may be extended through a constructed water course and into a natural water course. A constructed water course is defined in this rule as one that was constructed for irrigation, site drainage, or wastewater conveyance and has all of the following characteristics:

- Irrigation flows, stormwater runoff, or wastewater flows have replaced natural streamflow regimes
- The channel form is greatly simplified in lengthwise and cross sectional profiles
- Physical and biological characteristics that differ significantly from nearby natural streams
- A much lower diversity of aquatic species than found in nearby natural streams
- If the constructed water course is an irrigation canal, then it must have effective fish screens in place to qualify as a constructed water course.

Insignificant Discharge

The third criteria for granting an alternate mixing zone is if the discharge is insignificant. For the purposes of this rule, only filter backwash discharges and underground storage tank cleanups are considered insignificant discharges.

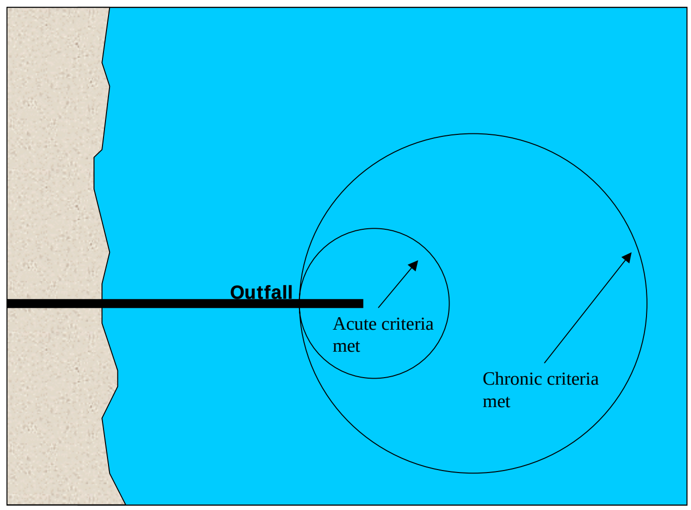

Figure 1.1: Two-Number Aquatic Life Critera

1.1.3 Mixing Zone and Zone of Initial Dilution (ZID)

One of the problems facing environmental managers is that definitions and requirements pertaining to the acute and chronic criteria and the definition of the ZID and mixing zone are not explicit in the rule. The rules provide general guidance and individual managers and permit writers are left to interpret the available EPA guidance for additional assistance. The Department relies on the guidance in the TSD and the Handbook to assign appropriately sized mixing zones in such a way as to be fully protective of beneficial uses. The Department has adopted the two-number aquatic life criteria for toxics, as well as the human health criteria as discussed in the TSD. For application of the acute and chronic aquatic life criteria, two different mixing zones may be identified (see figure 1.1). In the area immediately surrounding the outfall the acute and chronic criteria can be exceeded. This area is defined as the zone of initial dilution (the TSD defines this as the acute mixing zone). Outside of this defined area, the acute criteria must be met. The next area is known as the mixing zone (the TSD defines this as the chronic mixing zone). In this area the acute criterion must be met but not the chronic. Outside of the mixing zone the chronic criterion must be met. Generally, the ZID is sized to prevent lethality to passing organisms and the mixing zone is sized to protect the integrity of the water body as a whole. The outfall should be placed and designed to prevent adverse impacts to sessile or nonmotile organisms and to allow for fish passage.

The Department may change mixing zone requirements or require the mixing zone to be relocated if the Department determines the water quality within the mixing zone is having adverse affects on any beneficial uses of the receiving stream.

Whole Effluent Toxicity

Whole Effluent Toxicity (WET) is a term used to describe the aggregate toxic effect of an aqueous sample (e.g., whole effluent wastewater discharge or ambient receiving water) as measured according to an organism's response upon exposure to the sample (e.g., lethality, impaired growth or reproduction). WET tests replicate to the greatest extent possible the total effect and actual environmental exposure of aquatic life to effluent toxicants without requiring the identification of specific toxicants. WET testing is a vital component in implementing water quality-based toxic controls that are used for the National Pollutant Discharge Elimination System (NPDES) permitting process (EPA, Office of Wastewater Management).

The Department requires NPDES dischargers categorized as a major discharger or those with pretreatment programs to perform bioassays (also known as WET tests) on their whole effluent. Bioassays employ the use of standarized, surrogate organisms of the aquatic community and are a measure of the real biological impact from exposure to the toxicants.

The results of bioassays show at what concentrations the whole effluent is chronically and acutely toxic. These concentrations are compared with dilutions that are experienced at the edge of the ZID and mixing zone to determine whether acute or chronic conditions occur instream. If bioassay results demonstrate instream toxicity, the source must do another bioassay.

The Department follows the WET guidance and procedure developed by EPA and further discussion is beyond the scope of this document. More information can be obtained from EPA's website at: http://www.epa.gov/owm/wettest.htm

1.2 EPA rules and guidance

There is little mention of mixing zones in the federal rules. However, substantial information on mixing zones is contained in guidance documents. EPA addresses mixing zones briefly in the federal rules (40 CFR 131.13, General Policies)

> *States may, at their discretion, include in their State standards, policies generally affecting their application and implementation, such as mixing zones, low flows and variances. Such policies are subject to EPA review and approval.*

One other section of CFR 131 contains information regarding mixing zones specifically for 14 states and territories (CFR 131.36(c)(2)). In this section EPA defines what critical flows should be used for a receiving stream when evaluating mixing zones for toxic parameters. Despite the fact that Oregon was not one of these states, DEQ has typically used these critical flows as recommended in the TSD.

EPA guidance addressing mixing zones is contained in several documents, most recently including the *Water Quality Standards Handbook: Second Edition, August 1994* (The Handbook) and the *Technical Support Document for Water Quality-based Toxics Control, March 1991* (the TSD). These guidance documents will be discussed in detail below.

Much of the information contained in the Handbook is taken directly from the TSD. The Handbook is well organized and provides good general information on policy. The TSD provides the detailed technical information needed to conduct mixing zone analyses and to evaluate compliance with water quality standards. Where information was contained in both documents, it was summarized under the Handbook section because it is the most recent document. There will be some overlap or redundancy in the summaries of both documents below where appropriate.

1.2.1 Water Quality Standards Handbook

Chapter 5, General Policies, of the Water Quality Standards Handbook contains discussion and guidance on implementation of mixing zones. The underlying foundation for appropriately sizing of mixing zones is stated as follows in the Handbook:

> *Allowable mixing zone characteristics should be established to ensure that:*
>
> - *Mixing zones do not impair the integrity of the water body as a whole,*
> - *There is no lethality to organisms passing through the mixing zone; and*
> - *There are no significant health risks, considering likely pathways of exposure.*
>
> *EPA recommends that mixing zone characteristics be defined on a case-by-case basis after it has been determined that the assimilative capacity of the receiving system can safely accommodate the discharge. This assessment should take into consideration the physical, chemical, and biological characteristics of the discharge and the receiving system; the life history and behavior of organisms in the receiving sytem; and the desired uses of the waters. Mixing zones should not be permitted where they may endanger critical areas (e.g., drinking water supplies, recreational areas, breeding grounds, areas with sensitive biota)*

EPA recommends that State water quality standards should describe the State's methodology for determining the appropriate location, size, shape, outfall design, and in-zone quality of mixing zones. The Handbook describes each of these separately and each are summarized below:

Location

The area of a stream affected by a mixing zone depends in part on where the outfall is placed. To assure the mixing zone minimizes biological risk, the outfall should be placed and designed to minimize overlap of the mixing zone with biologically critical areas.

To address this issue, the Handbook states that biologically important areas should be identified and the location of the outfall be placed to protect these areas. Biologically important areas to be protected include continuous zones of passage that meet water quality criteria for free-swimming and drifting organisms, critical habitat for stationary species such as shellfish, spawning and rearing grounds and other critical habitat such as backwaters, coldwater refugia, and sloughs.

Size

Parts of this section on "size" are similar to the discussion on the types mixing zones discussed in section 1.1.3. Some of it is repeated here so that readers do not need to read the entire document to gain an understanding of this critical aspect of mixing zones.

The mixing zone should be sized to protect the integrity of the waterbody as a whole, prevent lethality to drifting organisms, and to prevent significant human health risks. Independently established mixing zone specifications may be applied to each one of these criteria. States that have both acute and chronic aquatic life criteria, may have two types of mixing zones. The zone immediately surrounding the outfall is typically defined as the acute mixing zone. The acute mixing zone must be limited in size to prevent lethality to drifting organisms. Outside of the acute mixing zone the acute criteria must be met. Outside of the acute mixing zone is the chronic mixing zone. The chronic mixing zone should be sized to protect the integrity of the waterbody as a whole. Outside the chronic mixing zone, chronic criteria must be met. Outside of this mixing zone the human health criteria must be met which is generally based on complete mix with the waterbody's harmonic mean flow.

The Department has adopted the acute and chronic aquatic life criteria and applies the above mixing zones as discussed earlier in section 1.1.3. However, the Department's rules do not use the term "acute mixing zone". Instead the term "zone of initial dilution" (ZID) is used. The "chronic mixing zone" is simply referred to as the "mixing zone".

People applying mixing zones should understand that conditions within the mixing zone would not allow for sensitive species to take up long term residence within the mixing zone. Survival, growth, and reproduction of some organisms may not occur within the mixing zone. Territorial organisms and benthic organisms are likely to be affected the most. Therefore it is important to limit the size of the mixing zone to protect the overall health of the waterbody.

The Handbook discusses mixing zones in terms of isopleths and limiting the concentration in these isopleths. Different taxa are more sensitive than others to various pollutants. The lower the concentration in these isopleths within the mixing zone, the less taxa are likely to be affected and less impact on the overall environmental community. Therefore getting rapid dilution is critical to limiting the concentrations of these isopleths and the overall size of the mixing zone.

To determine that the mixing zone is appropriately sized for aquatic life protection, conditions within the mixing zone can be compared to the following benchmarks:

1. If acute criteria are met throughout the mixing zone, no lethality should result from temporary passage through the mixing zone. If acute criteria are exceeded no more than a few minutes in a parcel of water leaving an outfall (assuming an exit velocity of 3 m/s and a mixing zone size of 50 times the discharge length scale, where the discharge length scale is equal to the square root of the cross sectional area of the pipe or port) this should also prevent lethality to passing organisms.

2. If a full analysis of concentrations and hydraulic residence times within the mixing zone indicates that organisms drifting through the centerline of the plume along the path of maximum exposure would not be exposed to concentrations exceeding the acute criteria when averaged over the 1-hour averaging period for acute criteria, then lethality to swimming or drifting organisms should ordinarily not be expected, even for rather fast-acting toxicants. In many situations, travel time through the acute mixing zone must be less than roughly 15 minutes if a 1-hour average exposure is not to exceed the acute criterion.

The above recommendations assume the effluent is repulsive to free-swimming organisms thus causing them to avoid the mixing zone. In cases where effluents containing toxic substances are attractive to free-swimming organisms, a denial of a mixing zone may be appropriate. If a state denies a mixing zone for certain substances, the criteria must be met at the end of the pipe.

The Handbook also states that if the total area affected by the mixing zone is small compared to the size of the waterbody (i.e. river segment), then the discharge is likely to have little effect on the integrity of the waterbody as a whole. This is only the case if mixing zones do not impinge on unique or critical habitat.

Shape

The shape of a mixing zone should be easily identified in a waterbody and avoid impingement on areas of critical habitat. The Handbook states that “shore-hugging” plumes should be avoided in all water bodies.

Outfall Design
Before designating any mixing zone, the State should ensure that the best practicable engineering design is used and that the location of the existing or proposed outfall will avoid significant adverse aquatic resource and water quality impacts of the wastewater discharge. Designing an outfall to produce rapid initial dilution is critical to limiting the concentrations in the isopleths surrounding the outfall, thereby limiting the impact to the aquatic community.

In-Zone Quality
Mixing zone must be free of the following:

1. materials in concentrations that will cause acutely toxic conditions to aquatic life;
2. materials in concentrations that settle to form objectionable deposits;
3. floating debris, oil, scum, and other material in concentrations that form nuisances;
4. substances in concentrations that produce objectionable color, odor, taste, or turbidity; and
5. substances in concentrations that produce undesirable aquatic life or result in a dominance of nuisance species.

Prevention of Lethality to Passing Organisms
The Handbook discusses four ways to prevent lethality to passing organisms:

1. Require that the criterion maximum concentration (CMC) be met at the end of the pipe. The CMC is the EPA national water quality criteria recommendation for the highest instream concentration of a toxicant or an effluent to which organisms can be exposed for a brief period of time without causing an acute effect. This is usually defined as the LC_{50} concentration.

2. Require the CMC be met within a short distance from the outfall under the following conditions:

    Use a high velocity discharge with an initial velocity of 3 m/s or more together with an acute mixing zone (or ZID) spatial limitation of 50 times the discharge length scale in any direction. This should ensure the CMC is met within a few minutes under practically all conditons.

3. If it is a low velocity discharge the most restrictive of the following conditions must be met:

    1. The CMC should be met within 10 percent of the distance from the edge of the outfall structure to the edge of the regulatory mixing zone in any spatial direction (this condition may as well be ignored because the TSD does not specifically describe how the size of a mixing zone should be determined).

2. The CMC should be met with a distance of 50 times the discharge length scale in any direction (the discharge length scale is defined as the square root of the cross sectional area of the outfall pipe or individual port).

3. The CMC should be met within a distance of five times the local water depth in any horizontal direction from any discharge outlet.

4. The discharge should provide data showing that a drifting organism would not be exposed to 1-hour average concentrations exceeding the CMC.

Computer modeling, dye studies, or monitoring studies could be conducted to provide information to satisfy the third or fourth alternative.

Human Health

The discussion on human health risks applies to long and short term health risks. The Handbook states that mixing zones must be sized and located such that they do not create significant health risks when considering likely pathways of exposure. Likely pathways of exposure include direct human intake as could occur when swimming, or indirect human intake such as through drinking water or fish tissue consumption. To reduce the short term health risks of waterborne diseases originating from fecal sources, the Department requires bacteria criteria to be met at the end of the pipe. This is not true with other states which allow mixing zones for bacteria discharges.

To address indirect human health risks, the Handbook emphasizes the location of drinking water sources should be taken into consideration before developing the location and size of a mixing zone where drinking water contaminants are a concern. Fish tissue contamination is also a concern for human health. Health risks originating from fish tissue contamination are typically long term and broader in scale than would be addressed through a mixing zone. However, mixing zones should be sized such that they do not encroach on areas of fish harvesting, particularly stationary species such as shellfish. Mixing zones may be denied if uncertainties regarding the protectiveness of the water quality criteria or the assimilative capacity of the receiving stream are present. Mixing zones for bioaccumulative pollutants should be severely restricted or eliminated.

Where Mixing Zones are not Appropriate

States are not required to allow mixing zones and may not be appropriate or may be denied in certain cases. Two situations in which a mixing zone could be denied are highlighted in the Handbook.

1. Denial of a mixing zone may be considered when a discharge contains bioaccumulative, carcinogenic, mutagenic, or teratogenic substances. The Handbook considers bioaccumulation potential to be significant when the bioconcentration factor (BCF) exceeds 100. The bioconcentration factor is chemical-specific and describes the degree to which an organism or tissue can acquire a higher contaminant concentration than its environment. Section 2.4.5 of the TSD should be reviewed for a detailed description of the BCF.

2. Another consideration for denial is when an effluent is known to attract biota. A literature review conducted by EPA demonstrated the majority of toxicants elicited an avoidance or neutral response at low concentrations. However, warmer effluent can attract biota and negate the avoidance response to toxicants.

Critical Low-Flows
The Handbook states that in establishing water quality standards, States may establish critical flows below which numerical water quality criteria do not apply. EPA recommends one of two methods for calculating critical low flows; the hydrologic method developed by USGS and a biologically based method developed by EPA. For protection of acute criteria, criterion maximum concentration (CMC), EPA recommends the hydrologic 1Q10 or the biologically-based 1B3 low flow. For the protection of the chronic criteria, criterion continuous concentration (CCC), EPA recommends the hydrologic 7Q10 or the biologically-based 4B3 low flow. Although water quality criteria within the mixing zone may be exceeded under these critical flows, the water within the mixing zone must at all times be free from substances that settle to form objectionable deposits; floating debris, scum, oil, or other matter; produce objectionable color, odor, taste, or turbidity; cause acutely toxic conditions; or produce undesirable or nuisance aquatic life. Definitions of the critical flows are discussed in more detail in the next section (Critical Design Periods for Waterbodies) which summarizes portions of the Technical Support Document pertaining to mixing zones.

1.2.2 Technical Support Document

The Technical Support Document for Water Quality-based Toxics Control (TSD) was originally written in 1985 and was most recently revised in 1991. The TSD provides guidance and procedures for developing water quality-based effluent limits for toxic pollutants in NPDES permits. Most of the mixing zone policies discussed in the Handbook, as summarized above, was extracted from the TSD. This information will not be discussed again. The TSD provides greater detail on critical low flows to be used for mixing zone analyses. This information is summarized below.

Critical Design Periods for Waterbodies
Section 4.4.2 of the TSD describes the critical design flows that should be used when performing mixing zone analyses for the various waterbodies below. The waterbodies are grouped as follows: Rivers and run-of-rivers reservoirs, lakes and reservoirs, estuaries and coastal bays, and oceans. DEQ rules do not allow discharges to lakes and therefore, will not be discussed in this document.

1. Rivers and Run-of-Rivers Resevoirs

The TSD defines rivers and run-of-river reservoirs as waterbodies that have a persistent throughflow in the downstream direction and do not exhibit significant natural density stratifcation. Critical design periods for these waterbodies are discussed in greater detail in appendix D of the TSD. The TSD recommends the use of the hydrologically or biologically based design flows. The critical flows are as follows.

- Aquatic Life

Acute criteria (CMC):	1Q10 or 1B3
Chronic criterion (CCC):	7Q10 or 4B3

- Human Health

Non-carcinogens:	30Q5
Carcinogens:	Harmonic mean flow

The 1Q10 is the lowest one day flow with an average recurrence frequency of once in 10 years. The 7Q10 is the lowest average 7 consecutive day low flow with an average recurrence frequency of once in 10 years. The 30Q5 is the lowest average 30 consecutive day low flow with an average recurrence frequency of one in 5 years. The harmonic mean flow is a long term mean flow value calculated by dividing the number of daily flows analyzed by the sum of the reciprocals of those daily flows.   The equation is:

$$\frac{n}{\sum 1/Q_{i-n}}$$

where n = number of daily flows
Q = flow

The biologically based design flows (1B3 and 4B3) are based on a method developed by EPA. This method directly incorporates the aquatic-life water quality criteria averaging periods and frequencies specified for the CMC and CCC (i.e. 1 day and 3 years for the CMC and 4 days and 3 years for the CCC). EPA performed a comparison of the hydrologically and the biologically based design flows and found the hydrologically based flows resulted in more excursions than allowed by the appropriate criteria. Regulated rivers may have a minimum flow in excess of these toxicological flows. In these cases, EPA recommends using the minimum flow.

EPA has two software programs that can calculate both types of design flows. Hydrologically based design flows can be calculated using the programs DFLOW or FLOSTAT, and biologically based design flows can be calculated using DFLOW. Both programs are available from EPA. The software package WQHYDRO (Aroner) also has the ability to calculate both types of design flows.

2.   Estuaries and Coastal Bays

The TSD defines estuaries as having a main channel reversing flow and coastal bays as having significant two-dimensional flow in the horizontal directions. For both water bodies, the critical design conditions recommended by EPA are based on a combination of the tides and the river conditions.

Because plume dynamics within an estuarine environment are so complex, discharge dilution can not be calculated simply based on the receiving stream critical low flow and the effluent discharge rate. Effluent mixing within an estuary is complicated by density stratification, tidal variation, wind effects, riverine inputs, and complex circulation patterns. The complex nature of the above factors requires site specific, empirical data to determine the critical dilution factors.

The TSD makes separate recommendations for estuaries without stratification and with stratification. In estuaries without stratification, the critical dilution condition includes a combination of low-water slack at spring tide for the estuary and design low flow for riverine inflow. In estuaries with stratification, a site-specific analysis of a period of minimum stratification and a period of maximum stratification, both at low-water slack, should be made to evaluate which one results in the lowest dilution. In general, minimum stratification is associated with low river inflows and large tidal ranges (spring tide), whereas maximum stratification is associated with high river inflows and low tidal ranges (neap tide).

In addition to evaluation of the above critical design conditions, an off-design condition should be evaluated as well. The recommended off-design condition for both stratified and unstratified conditions is that of maximum velocity during a tidal cycle. The off-design condition will likely result in greater dilution but it may carry the plume further downstream. Evaluations of this condition are necessary to assure toxic conditions are not carried downstream into critical resource areas such as shellfish habitat.

3. Oceans

The TSD refers to two documents that discuss critical design periods for ocean analyses (EPA, 1982 and Muellenhoff et al, 1985). The TSD provides a brief summary of these documents as they relate to mixing analysis for oceanic outfalls.

Like critical conditions for estuarine environments, oceanic critical periods must include analysis for periods of maximum and minimum stratification. The analysis must also include periods when oceanic conditions, weather conditions, or discharge conditions indicate that water quality standards are likely to be exceeded. The TSD suggests the 10^{th} percentile value from the cumulative frequency of each parameter should be used in the analysis.

Reasonable Potential Analysis

Chapter 3 of the TSD focuses on determining the need for permit limits in an NPDES permit. NPDES regulations under 40 CFR 122.44(d)(1) specify minimum requirements and general types of analyses necessary for establishing permit limits.

40 CFR 122.44(d)(1)(ii) states:

> *When determining whether a discharge causes, has the reasonable potential to cause, or contributes to an in-stream excursion above a narrative or numeric criteria within a State water quality standard, the permitting authority shall use procedures which account for existing controls on point and nonpoint sources of pollution, the variability of the pollutant or pollutant parameter in the effluent, the sensitivity of the species to toxicity testing (when evaluating whole effluent toxicity), and where appropriate, the dilution of the effluent in the receiving water.*

40 CFR 122.44(d)(1)(iii) states:

> *When the permitting authority determines, using the procedures in paragraph (d)(1)(ii) of this section, that a discharge causes, has the reasonable potential to cause, or contributes to an in-stream excursion above the allowable ambient concentration of a State numeric criteria within a State water quality standard for an individual pollutant, the permit must contain effluent limits for that pollutant.*

Based on these regulations, investigations must be made to determine if any pollutants in the effluent have the reasonable potential to contribute to violations of any water quality standards violations. This investigation is known as a "reasonable potential analysis". Chapter 3, section 3.3.2 describes the necessary steps in performing a reasonable potential analysis. This analysis is described in appendix B.

1.2.3 Allocated Impact Zones for Areas of Non-Compliance

EPA (Brungs, 1986) developed a procedure to look at mixing zones from a more holistic view. The procedure addresses the socioeconomic and ecological factors pertaining to wastewater discharges. Below is a summary of what is contained in the procedure:

- Present and future discharges in a waterbody or watershed should be considered together

- All available ecological and toxicological data or data that can be determined should be used in the analysis

- Waterbody uses are prioritized and assigned numerical relative values based upon socioeconomic considerations. Similar considerations are necessary to select an appropriate level of protection. These decisions are part of the risk management process, and are separate from the risk assessment parts conducted by scientists and engineers.

- Each discharger is assigned a fraction of the available environmental value of a waterbody based upon an allocation model and expressed area.

- If the assigend area is too limiting, alternatives such as discharge relocation or redesign, toxicity reduction, termination of limiting process, etc., are to be considered. Purchase of unneeded allocation from another discharger is appropriate.

In essence, this document states that mixing zones should be viewed holistically and be addressed very similar to total maximum daily loads (TMDLs). The document discusses that obtaining all the data necessary for this analysis is extensive and not practicable, but that some of the initial steps are reasonable.

The author chooses to use the term "Allocated Impact Zones" (AIZ) in place of mixing zones. This term was chosen because for several reasons. It avoids confusion with the historical definitions of mixing zones. The word allocated was chosen because it reflects the fact that all discharges should be evaluated holistically as is the case with wasteload allocations. The word impact is descriptive of the fact there is potential for adverse impact on aquatic life when water quality standards are allowed to be exceeded. This term is used interchangeably throughout the discussion of this document.

The allocated impact zone procedure is broken down into ten steps which is the core part of the document. The ten steps in chronological order are as follows:

1. Determine the need for allocation
2. Establish waterbody boundaries
3. Analyze current and future discharge data
4. Analyze ecosystem data
5. Develop environmental mapping
6. Assign relative values
7. Determine level of protection
8. Select allocation procedure
9. Allocate AIZ
10. Specify quality within AIZ

Only the first five steps will be summarized because the remaining steps are beyond the scope of this document. For additional information and an example of this process, the document should be read in its entirety.

1. <u>Determine Need for Allocation</u>: The focus of this step is to allocate the impact zones from dischargers in a holistic manner. Because a case-by-case approach has led us to the current water quality problems, this approach is not likely to work in the future. A holistic approach is needed to address water quality problems adequately. In addition, the most cost-effective approach is to address all sources at the same time.

2. Waterbody Boundaries: Waterbody boundaries need to be defined that would determine which dischargers should be analyzed together. If the boundaries are too small there is risk in maintaining the present case-by-case method, if the boundaries are too large, the are would not be manageable.

   There are a variety of parameters that could affect how the waterbody boundaries are determined. The physical, chemical, or ecological characteristics of a waterbody could be used to define the boundary. A river pool between dams, a lake, an estuary, or a water quality limited segment are all examples of defined boundaries.

3. Discharge Data: All point source discharges should be identified for the waterbody being evaluated. Discharge information such as flow rates, conventional parameters, toxic parameters and any seasonal or diurnal variation should be collected. Information should also be gathered on future changes either in present discharges or planned future ones.

4. Ecosystem Data: The first step is to identify and gather all available data. Where data gaps become apparent, a decision needs to be made as to whether additional data needs to be collected. Ecosystem data can include but not limited to the following:

- Public and private drinking water supply intakes.
- Ambient water quality data.
- Water quality and pollutant transport models already available for the waterbody of concern.
- Available fish data such as migratory pathways, spawning and nursery areas.
- Threatened and endangered species
- Other biological data such as primary producers and macroinvertebrates.
- Recreational and other uses.

5. Environmental Mapping: Environmental mapping is a tool that is useful for displaying all available data for a given waterbody. Various parameters can be overlayed to show relationships that may exist and to demonstrate areas of concern or needed protection. The ecosystem data above are the types of parameters that should be mapped. Other data within the waterbody that should be considered for mapping includes other allocated impact zones, beaches, parks, fishing areas, and areas of future planning.

The remaining steps of this process are too complicated to address in this document and are beyond the scope of what would be expected from a mixing zone study. Although, there are some ideas that can be gained from the final steps and possibly incorporated into a mixing zone analysis.

At the end of the document, the author provides a historical perspective to mixing zones collected from older documents. Some of these points are summarized below:

- The U.S. Department of the Interior (1968) recommended a zone of passage of 75% of the cross-sectional area and/or volume of flow of the stream or estuary.

- Mixing should be accomplished as quickly as possible through devices which insure that the waste is mixed with the allocated dilution water in the smallest possible area.

- Since all life stages, such as spawning and larval development, are necessary functions of aquatic organisms and are not protected in allocated impact zones, it is essential that adequate portions of every waterbody are free of these zones.

- The effluent plume may be identified at distances or in places outside the allocated impact zone.

- The mixing zone is a place to mix and not a place to treat effluents.

- The permissible size of the mixing zone is dependent on the acceptable amount of damage.

- The size and shape of the mixing zone should be specified so that both the discharger and the regulatory agency knows its bounds.

- A mixing zone should be determined taking into consideration unique physical and biological features of the receiving water.

- Any mixing zone must be limited to a temporal and spatial distribution which will assure the protection and propagation of a balanced, indigenous community of shellfish, fish and wildlife in and on the receiving waterbody.

- The acceptable size for a mixing zone depends also on the number of mixing zones on a body of water. The greater the number, the smaller each must be. In this connection, future growth of industry and population must be considered.

Chapter 2

Mixing Zone Report

DEQ receives mixing zone studies from permittees and consultants on a regular basis. Every mixing zone report is done differently which can make reviewing the reports difficult. Each report needs to be reviewed in detail for sound modeling methodology and adherence to state and federal rules and guidance. To aid DEQ in expediting the review process and to assist consultants and permittees in preparing reports, a description of the minimum requirements for a mixing zone report is discussed below.

Historically, mixing zone studies have focused primarily on dilution results. As officials in charge of protecting the environment have become more knowledgeable on impacts of discharges to beneficial uses, the need to expand the scope of mixing zone studies has become apparent. Dilution results are a critical product of mixing zone analysis. In addition, information such as aquatic life presence, drinking water sources, plume dynamics and dimensions are needed to thoroughly evaluate the potential impacts of the discharge to the receiving water body and to appropriately size the mixing zone.

In the past, it was common practice to determine the dilution needed to meet water quality standards at the edge of the mixing zone and size the mixing zone accordingly. This practice resulted in mixing zone lengths on the order of miles sometimes. This clearly does not meet the goals and requirements of the CWA. The mixing zone must be placed and sized based on careful consideration of the impacts to the beneficial uses of the water body. Once the size of the mixing zone has been established, compliance with water quality standards may be determined. If particular parameters do not meet water quality standards at the edge of the mixing zone, treatment options need to be identified and implemented to reduce the pollutants of concern.

A mixing zone study needs to take a holistic approach to protecting the aquatic resources. There are five sections that should be included in a mixing zone report:

1. Existing Mixing Zone Description
2. Environmental Mapping
3. Physical Mixing Parameters
4. Mixing Zone Modeling
5. Compliance with Water Quality Standards

2.1 Existing Mixing Zone Description

A complete characterization of the present mixing zone should be included in the report. If the mixing zone study includes placement of a new outfall, the description of the proposed outfall should be described as well. Include in this description:

- A diagram of the placement of the discharge in relation to the cross section of the receiving stream needs to be provided. A plan view of the discharge should be provided as well including the locations of the mixing zone and zone of initial dilution (ZID) boundaries. The diagram should clearly show all appropriate dimensions as listed below (see figure 2.1):

    - Width and depth of receiving water body for all critical flow conditions (7Q10, 1Q10, other critical flows)

    - Local water depth at placement of outfall

    - Distance of outfall from the bank

    - Height of outfall above the bottom

    - Diffuser and port dimensions and configuration

        - Diffuser length
        - Number of ports (note and describe blocked or non-functioning ports)
        - Orientation angles

            - THETA - vertical angle of discharge between the port centerline and a horizontal plane (-45° and 90°).

            - SIGMA - horizontal angle of discharge measured counterclockwise from the ambient current direction (x-axis) to the plan projection of the port centerlines (0° to 360°).

            - BETA - relative orientation angle measured either clockwise or counterclockwise from the average plan projection of the port centerlines to the nearest diffuser axis (0° to 90°).

            - GAMMA - average alignment angle of the diffuser pipe measured counterclockwise from the ambient current direction (x-axis) to the diffuser axis (0° to 180°)

- The description of the mixing zone and the ZID, as it appears in the permit.

- The river mile and latitude and longitude for the location of the outfall.

- Photographs of the area of discharge (upstream and downstream). Photographs of the area provide valuable information particularly to those who have not visited the outfall site and are a good tool for historical reference.

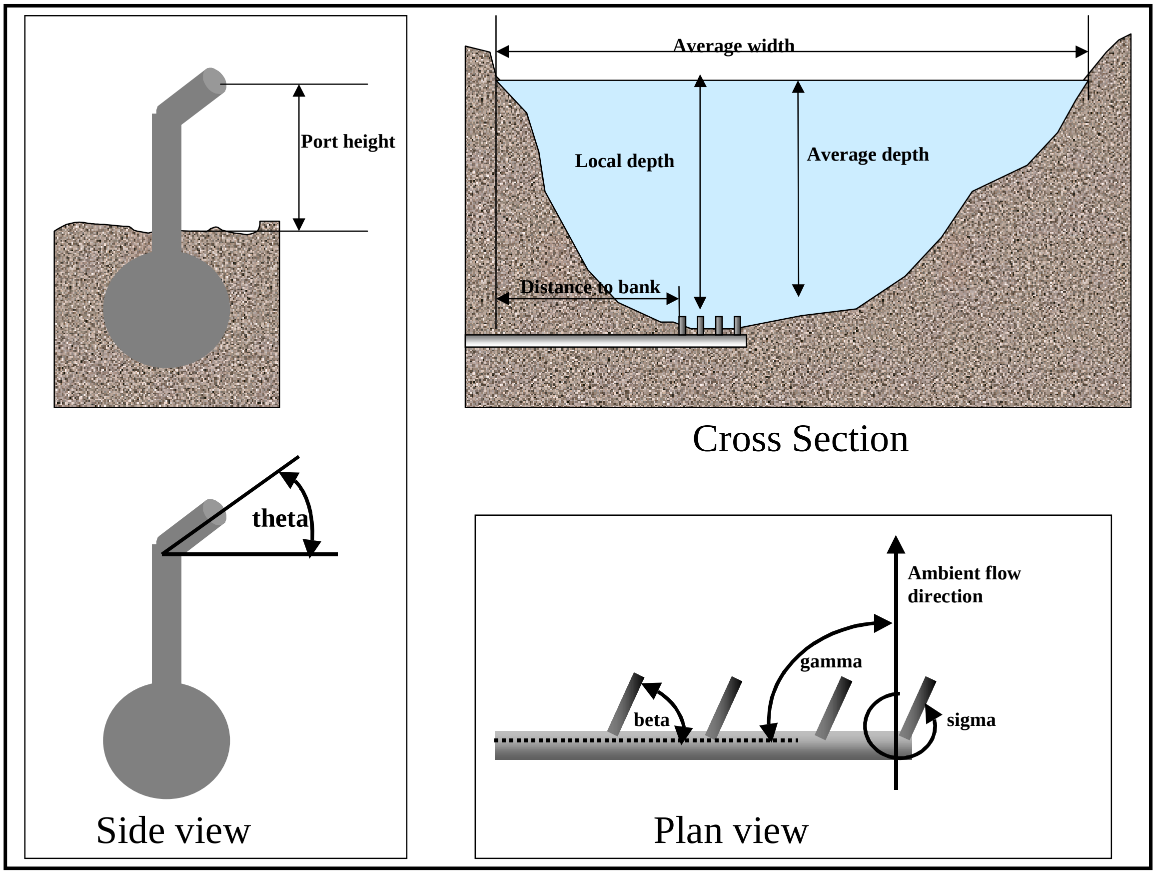

Figure 2.1: Cross section and diffuser diagram

2.2 Environmental Mapping

Environmental mapping has many definitions or meanings associated with it. In the case of mixing studies, environmental mapping is a method to characterize and map specific habitats, critical resource areas, and other beneficial uses within the segment of the waterbody being discharged to. Historically, mixing zone studies have focused primarily on dilution analysis. While this is an important product of a mixing zone study, it is only a small piece of information needed to adequately assess the appropriateness of the size and location of the mixing zone. The Department needs to have information about the biological community, unique habitat, recreational uses, and other beneficial uses that may be impacted by this discharge. This information should be mapped and characterized so that informed decisions can be made to ensure the size and placement of the mixing zone does not jeopardize the overall health of the system. The reason for mapping the information is to provide a reference for interpreting and displaying physical information in an easy format to visualize and understand. In addition, environmental mapping can be an excellent tool used to raise the environmental consciousness among the public.

Environmental mapping, for the purposes of this report should describe in detail and map (where appropriate) the following items:

1. Unique habitat
    - Benthic organisms
    - Shoreline habitat
    - Shellfish habitat
    - Cold water refugia
    - Physical structures expected to attract fish
2. Measure of biologic integrity - impairment (Rapid Bioassessment - DEQ)
3. Salmonid presence and use
    - Spawning/holding/rearing
    - Cold water refugia
    - Migratory pathways
4. Endangered species presence
5. Other wildlife (waterfowl, beaver, river otter, etc)
6. Describe other point sources upstream and downstream
7. Drinking water intakes
8. Other beneficial uses (fishing, boating, swimming, navigation,etc)

The environmental mapping exercise should not only discuss present conditions, it should also include any information on historical data that is available. This information will be useful to gain an understanding of the historical perspective and conditions before man's intervention.

This information is critical to holistically assessing the impacts of a discharge to a given water body. As discussed in the Handbook and the TSD, one condition for allowing mixing zones is to ensure they do not impair the integrity of the water body as a whole. Environmental mapping is an integral tool to assure that the mixing zone minimizes risk to beneficial uses by minimizing superimposition of mixing zones and unique habitat. With this information, the impact of the discharge on them can be assessed. This information could lead to the need to improve wastewater treatment or changes in the size and location of the mixing zone. Environmental mapping will also create a more robust data set for the Department to evaluate the cumulative impacts of point sources on a water body or watershed.

2.3 Physical Mixing Characteristics

This section of the report should describe physical mixing characteristics that occur initially as effluent mixes with receiving water (near field) and further downstream after initial mixing is complete (farfield) (these terms are described in detail in the next chapter and defined in the glossary). Mixing processes are largely controlled by two factors: Ambient conditions and discharge characteristics. The information that should be provided to describe mixing is summarized below.

2.3.1 Ambient Conditions

Flow Statistics

The dilution near an outfall is dependent upon several factors. Stream flow is a significant factor influencing dilution. To assure impacts to receiving waters are minimal, mixing zones should be designed under reasonable critical conditions. These critical flows vary depending on the potential impact. A short, very infrequent condition for acute toxicity, and a slightly longer period for chronic toxicity. Longer term human health impacts are evaluated on a longer term flow statistic.

Table 2.1 : Flow statistics summary

Flow Statistic	Definition	Criterion
Rivers		
7Q10	Lowest average 7 consecutive day low flow with an average recurrence frequency of once in 10 years.	Chronic
1Q10	Lowest 1 day flow with an average recurrence frequency of once in 10 years.	Acute
30Q5	Lowest average 30 consecutive day low flow with an average recurrence frequency of one in 5 years.	Human health (non-carcinogenic)
Harmonic mean	The number of daily flows divided by the sum of the reciprocals of those daily flows.	Human health (carcinogenic)
Estuaries and Coastal Bays		
Without Stratification		
Critical dilution	Low-water slack at spring tide combined with riverine critical low flow	Chronic and Acute
With Stratification		
Minimum stratification	Low-water slack, high tidal range (spring tide), and low riverine inflow	Chronic and Acute
Maximum stratification	Low-water slack, low tidal ranges (neap tide), and high riverine inflow	Chronic and Acute

Critical receiving stream flow rates will be needed to evaluate dilution and mixing characteristics for the protection of beneficial uses. For streams and rivers the 7Q10, 1Q10, 30Q5, and the harmonic mean flow should be calculated at a minimum. The 7Q10 critical flow rate is needed to evaluate protection of aquatic communities for the chronic toxicity. The 1Q10 is necessary for evaluating acute conditions. The 30Q5 is used for evaluating non-carcinogenic human health criteria and the harmonic mean flow is needed for evaluating carcinogenic human health criteria. Human health impacts are determined based on complete mix with the receiving waterbody. Separate critical conditions should be evaluated for estuarine environments. The condition that provides the lowest dilution should be used. This will vary from site to site due to the complex nature of estuarine environments. Typically the worst case conditions occur either at maximum stratification or minimum stratification both during slack water periods. Table 2.1 provides a summary of the typical critical flow statistics that are used in mixing zone analysis and suggested by the TSD.

Other flow rates may need to be calculated depending on the beneficial uses and the hydraulic conditions of the receiving stream. For example, flow rates may need to be determined that correspond with various critical life stages and migration patterns of salmonids and other aquatic life. If stream flow is controlled by dam releases, other statistical flow rates may need to be determined that are more appropriate. Discharges that vary seasonally will need to be evaluated based on a seasonal flow analysis. If the situation is complex and there is uncertainty in what the critical conditions are, the details should be worked out with the Department to ensure worst case conditions are being simulated.

Cross Sectional Area
Cross sectional information is needed to review and perform mixing modeling exercises. The cross section may constrain plume spreading vertically and laterally. Some models assume an infinite receiving waterbody and may not be appropriate depending on boundary interactions. The cross sectional profile (width and depth) of the receiving stream within the mixing zone and the ZID need to be described and diagrams should be included. If farfield analysis is important then cross sectional areas further downstream should be included as well, particularly if there are significant changes in the bathymetry. This information should have already been described in the first section "Existing Mixing Zone Description". If a new outfall or diffuser is being proposed, the same information needs to be provided for the new outfall/diffuser as described in the "Existing Mixing Zone Description" section. A diagram with similar information as figure 2.1 should be provided for the new outfall/diffuser configuration.

Velocity Profile
Velocity greatly influences plume dynamics and plume shape. Resulting dilution is very sensitive to stream velocity for most scenarios. Velocity measurements that correspond to the critical flows identified need to be described. If there are significant changes in velocity with respect to depth, a velocity profile should be included. This is more important for the nearfield analysis than the farfield analysis. If the receiving stream is tidally influenced, the velocity dynamics will need to be described over the tidal cycle.

Density/Temperature/Salinity Profile
The salinity and/or temperature profile affect ambient density which can influence plum dynamics due to buoyancy forces. Streams or estuaries that are stratified either due to temperature or salinity need to be described and diagrammed. Stratification can greatly affect mixing and is important input needed for mixing zone models. Again, for tidally influenced cases, salinity and temperature profiles need to be described over the full tidal cycle. Maximum and minimum stratification conditions should be characterized as well as these typically can be worst case conditions.

Manning's Roughness Coefficient
Manning's roughness coefficient (n) is a measure of the friction at the stream bottom. The channel morphology should be described and Manning's n estimated based on this description. Table 2.2 gives some estimates of typical values that are used in stream modeling.

Table 2.2 : Estimates of Manning's n

Manning's n Coefficients	
n	**Natural Streams**
0.30	Clean and straight
0.35	Major rivers
0.40	Sluggish with deep pools

2.3.2 Discharge Characteristics

Outfall Description/Configuration
A detailed outfall description, including the diffuser configuration, is critical information needed as input for mixing zone models. The information needed as describe previously in section 2.1, "Existing Mixing Zone Description".

Effluent Flow Rates
The design flow rates for the facility should be included in this report. Typically, for domestic wastewater facilities, the average daily dry weather flow should be used to model chronic conditions. The maximum daily dry weather flow should be used for modeling acute conditions. Dry weather flow rates are used because the summer period is typically the most critical time for low dilution and higher instream concentrations. Other flow rates may need to be used depending on the timing with environmental factors (salmonid migration, shellfish harvesting, etc).

For industrial facilities, the maximum monthly average is typically used to model chronic conditions if the flow rate is fairly constant throughout the year. The maximum weekly average should be used for acute conditions. If the industrial facility has seasonal flow fluctuations, other flow rates will need to be determined. These flow rates should be determined based on the effluent flow rate, receiving stream flow rate, and other environmental conditions.

Provide daily flow rates and monthly average flow rates for the past five years in digital format. Also include a discussion on projected flow rates for the next 20 years.

Temperature/Density
Describe the temperature and/or density of the effluent for the critical time periods. This information is needed for the modeling exercises and critical in predicting the behavior of the discharged effluent.

A summary table of the ambient and discharge information needed is shown below (see table 2.3).

Table 2.3: Summary information for ambient and discharge data

Ambient Data Requirements	
Critical flow statistics	1Q10, 7Q10, 30Q5, harmonic mean, others
Receiving water body cross section/bathymetry	Width, depth, at critical flows.
Velocity	Vertical profile, relationship to flow.
Density/Temperature/Salinity profile	Stratification layers, pynoclines (seasonal and tidal variations)
Manning's n	Roughness of stream bottom.
Discharge Data Requirements	
Outfall description	Cross section and plan view of outfall (see figure 2.1)
Diffuser description	Pipe diameter, diffuser length, port diameter, number of ports, port configuration
Effluent flow rates	
Domestic dischargers	Average daily dry weather flow: Chronic criteria
	Maximum daily dry weather flow: Acute criteria
Industrial dischargers	Maximum monthly average: Chronic criteria
	Maximum weekly average flow: Acute criteria
All dischargers	Other flow rates may be need to be evaluated depending on specific conditions

2.4 Mixing Zone Modeling

Several numerical models are available for simulating mixing. The Department usually uses EPA supported models. Different models perform better under specific conditions. The models should be selected that best match the conditions being simulated. This section of the report should describe the fundamental aspects of modeling the discharge. This should include an explanation of the various models considered and the justification for model(s) used. The results of the modeling exercise should be described in detail.

Model Selection and Application
When presenting a mixing zone analysis, the reason for selecting the model(s) used should be described specifically and describe why other mixing zone models were not used. Provide the version number of the model(s) used. If more than one model was used or if a different one was used for the farfield analysis than the nearfield analysis, describe the rationale. If dissolved oxygen is a parameter of concern, the model used for this anlaysis needs to be described as well. Variables such as reaeration rate and BOD decay rate should be reported and the rationale for using those values explained. If techniques such as the "imaging method" are being employed, a complete discussion of this method needs to be included. Included in this discussion should be a demonstration that underlying assumptions for using this method were not violated.

Description of Mixing and Dilution
The results of the modeling exercise should be discussed here and input and output files of appropriate model scenarios should be provided electronically and in paper format. Historically, emphasis was placed only on dilution results. Dilution is a key result of the modeling exercises but not the only result that should be reported. A description of the physical mixing within the near field and far field should be included. Define where the plume loses its initial momentum and where the far field process begins. Describe any stratification of the plume that occurs, when the plume interacts with the surface, or other boundary conditions. Describe the shape of the plume in three dimensions and whether there are any buoyant upstream intrusions. Discuss whether there are any near field dynamic attachments. This is important information needed to determine whether aquatic life resources and other beneficial uses are being protected. Providing plume graphics in the cross section and plan view is an excellent way of describing the plume characteristics. The dilution at the edge of the ZID and the edge of the mixing zone should be reported. Describe the sensitivity analysis including a discussion about which variables were most critical to the model output. All the above information needs to be described for each condition modeled.

Model Results Table
A table that displays the modeling results should be included that lists the input parameters and results achieved for each modeling scenario. Include all input parameters that are needed run the model(s). The information to be placed in the table should have already been described above. This information is useful for the mixing zone reviewer to have all critical information summarized in one table. The table can then be used to review the inputs and results for the various model scenarios also to use the table to perform additional modeling runs.

2.5 Compliance with Water Quality Standards

In order to determine compliance with water quality standards it is necessary to match chemistry data with the physical and mixing data describe above. Both effluent and receiving water quality data is needed. Compliance with water quality in a mixing zone is often driven by toxics. Information on chlorine and ammonia is needed. Data for other toxics should be provided as well.

Effluent Water Quality Data
Data will need to be provided that characterizes the effluent water chemistry. The report should include summary statistics for all parameters that are monitored for as required by the permit. Other parameters may need to be characterized as well such as biochemical oxygen demand (BOD), carbonaceous biochemcial oxygen demand (CBOD), total suspended solids (TSS), turbidity, dissolved oxygen, temperature, pH, nutrients (nitrate-nitrite, ammonia, total kjedahl nitrogen, ortho and total phosphate), alkalinity, hardness, metals, conductivity, metals, fecal coliform and E. coli (see table 2.4). Summary statistics should include the number of data points, maximum, minimum, average, median, 99th, 95th, 90th, 75th, and 25th percentiles. Diurnal fluctuations will need to be described for parameters that are diurnal in nature (dissolved oxygen, pH, temperature). Seasonal fluctuation should be described for parameters that vary from month to month. A discussion of recent bioassay results should be included here as well. The discussion should focus on acute and chronic toxicity at the ZID and the edge of the mixing zone.

Summary information should be provided in the report, but the raw data and the summary statistics should be provided electronically in a spreadsheet format. Depending on the specific source, all the above data may not be needed. This should be discussed with the Department when developing a mixing zone scope of work.

If the stream is water quality limited, effluent water quality data for those parameters or related parameters needs to be provided. Information about the water quality-limited streams can be obtained from the Deparment's web page at http://waterquality.deq.state.or.us/wq/303dlist/303dpage.htm.

Table 2.4: Water Quality Parameters

Parameter	**Applicability**
BOD/CBOD	Compliance with dissolved oxygen standard/farfield analysis
TSS	Permit parameter
Turbidity	Compliance with turbidity standard
Dissolved oxygen	Compliance with dissolved oxygen standard/near field affects
Temperature	Compliance with temperature standard/affects ammonia toxicity/affects decay rates
pH	Permit parameter/affects metals partitioning/affects ammonia toxicity/compliance with pH standard at edge of ZID and MZ
Ammonia	Compliance with ammonia criteria at edge if of ZID and MZ/dissolved oxygen modeling/nutrient dynamics
Chlorine	Chlorine toxicity
Nitrogen/Phosphorous components	Nutrient dynamics/affects on dissolved oxygen and pH/algal growth
Alkalinity	Compliance with pH standard at edge of ZID and MZ
Hardness	Compliance with metals criteria at edge of ZID and MZ
Conductivity/TDS	Conservative tracers
Metals	Compliance with metals criteria at edge of ZID and MZ
E. coli/Fecal coliform	Permit parameter
Bioassays	Compliance with WET at edge of ZID and MZ

Ambient Water Quality Data
Ambient water quality data will be needed to evaluate whether the discharge meets water quality standards. The same parameters should be evaluated as those discussed above. Data being collected and gathered should focus on the critical time periods (i.e. summer months, spawning periods, migration periods, etc.). The Department has historical data on most of the major rivers and streams in Oregon. It also has conducted intensive water quality surveys on many of the water bodies. This information is available though the DEQ laboratory. Other ambient water quality data for Oregon's rivers and streams are available through the US Geological Service (USGS), the US Forest Service, the National Marine Fisheries Service (NMFS), Oregon Department of Fish and Wildlife (ODFW), and other local, state, and federal agencies. If there is insufficient ambient water quality data available, the permittee will need to develop a monitoring plan to address the lack of data. Ambient chemistry data may need to be collected as part of the field mixing zone study and/or included as a permit condition in future permits. These details should be worked out with the Department.

Reasonable Potential Analysis
Under federal law, the Department has the responsibility to perform reasonable potential analysis. Reasonable potential analysis is a method for determining whether effluent parameters have reasonable potential to cause or contribute to a water quality standard violation. Effluent parameters that have reasonable potential need to have limits placed in their permit. The combination of modeling results, effluent water quality and ambient water quality data will be used by the Department to determine whether the discharge causes, has the reasonable potential to cause, or contributes to an excursion of a water quality criteria.

The Department has developed a spreadsheet for performing reasonable potential analysis based on the EPA method outlined in the TSD. This spreadsheet is available from The Department. The permit writer for your source should be able to provide a copy of this spreadsheet. Reasonable potential analysis is discussed in the TSD section and steps are outlined in appendix B. Example output from the spreadsheet is also included in the appendix.

Protection of Beneficial Uses
In addition to demonstrating compliance with water quality standards, the mixing zone study should include a thorough discussion on how the beneficial uses of the water body are being protected. The protection of beneficial uses discussed in section 2.2 (Environmental Mapping) should be demonstrated in this section. List each beneficial use and how this discharge is not adversely impacting it. Beneficial use protection should include where appropriate discussions on migratory pathways, spawning and rearing grounds, shellfish areas, endangered species, macroinvertebrates, drinking water sources, swimming, fishing and other water recreation, and any other beneficial uses.

Chapter 3

Mixing Zone Theory

3.1 Hydrodynamic Mixing Processes

This section will provide an introductory review into the physical mixing behavior of wastewater discharged into a receiving water body. A complete discussion of hydrodynamic mixing processes is beyond the scope of this document. References are included for those readers who wish to dive deeper into the subject. This section is intended to provide the reader with enough knowledge to understand the fundamentals of physical mixing processes. This will hopefully give a new mixing zone modeler enough information to get started with performing mixing zone analysis and review. For those already well-educated in hydrodynamic mixing processes, this section may be simply a review of what you already know.

Three Physical Principles Governing Mixing
There are three physical principles that govern the physical mixing of effluent in a water body.

1. Conservation of mass (mass flux = mass/time)

   The mass flux is defined as the mass of fluid passing a jet cross-section per unit time. The conservation of mass is critically important for determining concentrations of pollutants within the discharge.

2. Conservation of momentum (momentum flux = (mass x velocity)/time)

   Momentum is the product of an object's mass and velocity. In mixing processes momentum flux is defined as the amount of streamwise momentum passing a jet cross-section per unit time. It is helpful to think of it as the units indicated above; mass x velocity/time. with the key component being velocity. The kinetic energy (the energy associated with motion) generated by the velocity of the fluid is conserved.

3. Conservation of energy (buoyancy flux = (mass x acceleration)/time)

   Buoyancy (negative or positive) arises from the density difference between two fluids. Buoyancy flux is defined as the submerged weight of the fluid passing through a cross-section per unit time. Buoyancy force is a function of the acceleration due to gravitational forces. Hence the critical component of conservation of energy is acceleration. This energy is potential or stored energy. Energy that is created by the density difference between the ambient and discharge fluid must be conserved.

Jet and Plume Definitions

Before going further into this subject matter, two terms need to be defined; jet and plume. These two terms are often used interchangeably, but for discussions on mixing processes, defining the terms separately is important.

Jet – A high velocity discharge relative to the ambient velocity where only the initial momentum flux causes turbulent mixing (see figure 3.1).

Plume – A discharge with little or no initial momentum in which the buoyancy flux is the principal cause of turbulent mixing.

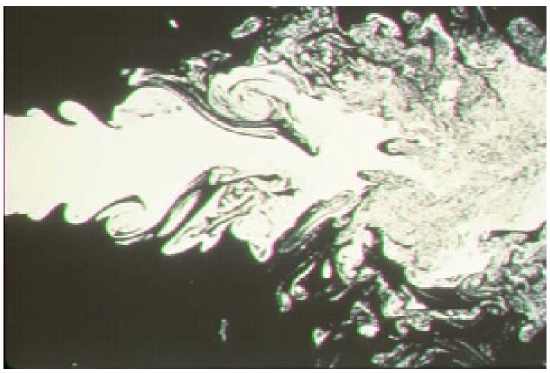

Figure 3.1: Scherlin photograph of a turbulent buoyant plume, showing the turbulence of mixing. (Photo: Schon, Univ. of Lyon)

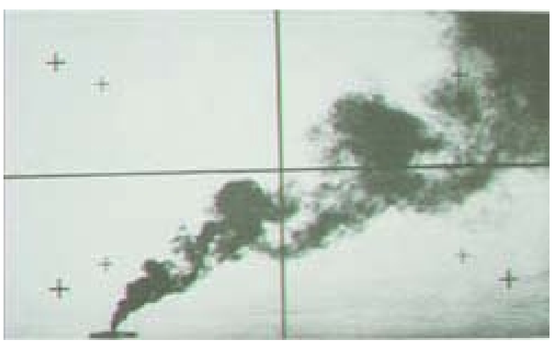

Figure 3.2: A buoyant jet in a laboratory experiment with crossflow (Source: L. Fan, CIT)

A discharge that is derived from sources of both momentum and buoyancy is termed a buoyant jet (see figure 3.2). Given enough time and distance, a buoyant jet will eventually lose its momentum and act like a plume.

A fire hose shooting out water at a fast initial velocity is an example of a jet. A jet will overpower the receiving water velocity and any buoyancy differences between the discharge and ambient fluid. An example of a pure plume would be a heating pad placed at the bottom of a pool. The heating pad would warm up the water immediately surrounding the pad. The buoyancy force created by the warm water would cause the fluid to rise as a pure plume. There is no initial velocity hence no initial momentum. Momentum is eventually created due to the potential energy of the warmer, buoyant fluid being converted into kinetic energy.

Characteristics Affecting Mixing

The mixing behavior of a discharge is affected by the combination of two characteristics: Discharge characteristics and ambient conditions.

Discharge characteristics include the following:

- Discharge velocity
- Discharge flow rate
- Port or pipe diameter
- Diffuser/port configuration and geometry
- Elevation of port or pipe off the bottom

- Density of the discharged fluid

Ambient conditions include the following:

- Ambient velocity
- Ambient flow rate
- Lateral cross sections/bathymetry
- Ambient density profile

Near and Far field Processes

The physical mixing process can be conceptualized in two distinct regions: the **near field** and the **far field**. The near field region is defined where initial jet momentum, buoyancy flux, and outfall characteristics control the mixing process. Designers of diffusers and outfalls can sometimes have some affect on initial mixing in this near field region. When the discharge flow encounters a boundary such as surface, bottom, or internal ambient density stratification layer, the near field region ends and the transition to the far field begins.

The far field region is defined as where ambient processes dominate the mixing process. Once the discharge interacts with a vertical boundary, the mixing processes are primarily a function of the ambient conditions characterized by the longitudinal advection of the mixed effluent by the ambient velocity. The discharge in the far field loses its "memory" of its initial conditions and mixing is now mainly a function of the ambient conditions.

In simpler terms the near field region is typically the region that is controlled by the characteristics of the discharge itself (discharge flow rate, port diameter, etc) and the far field region is the region that is controlled by ambient conditions (ambient velocity and density field, cross sectional area, etc.).

Near Field Processes

Figures 3.3-3.5 illustrate the three types of surface boundary interactions that can occur in the near field; surface boundary, intermediate stratification boundary, and the bottom. There are a variety of interactions that can take place at these boundaries depending on the characteristics of the discharge and ambient conditions. Describing all of these interactions is beyond the scope of this document but some of the more important ones can be discussed.

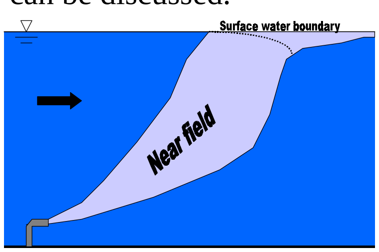

Figure 3.3: Surface Boundary

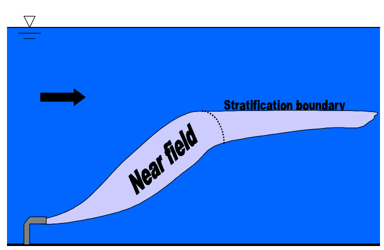

Figure 3.4: Stratification Boundary

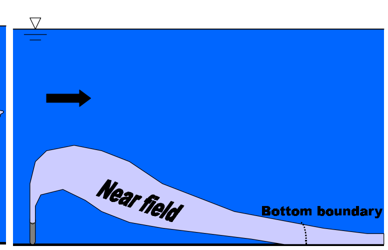

Figure 3.5: Bottom Boundary

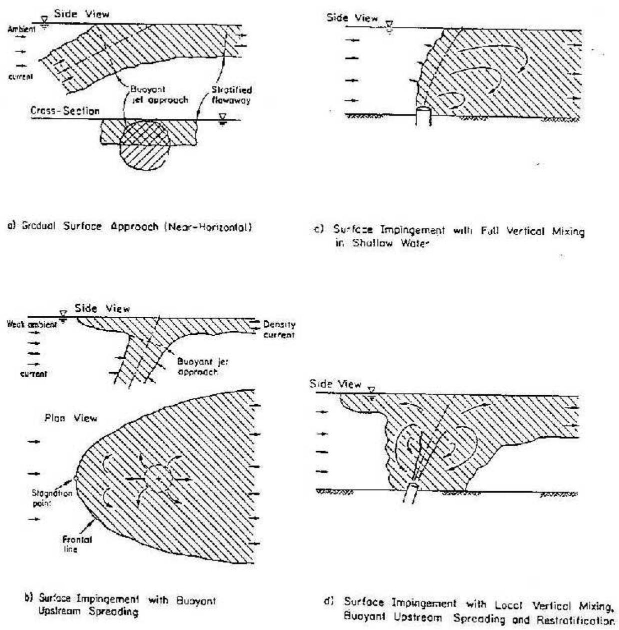

Figure 3.6 : Examples of surface boundary interactions (CORMIX manual)

Several types of surface boundary interactions are illustrated in figure 3.6. If a buoyant jet is bent-over by a cross-flow, it will gradually approach the surface, bottom or terminal level and will undergo a smooth transition with little additional mixing (3.6a). However, a jet impinging normally, or near-normally, on a boundary will rapidly spread in all directions. Mixing conditions at this impingement point can take on one of the following forms: (a) If the flow has sufficient buoyancy it will ultimately form a stable layer at the surface (3.6b). In the presence of weak ambient flow this will lead to an upstream intrusion against the ambient current. (b) If the buoyancy of the effluent flow is weak or its momentum very high, unstable recirculation phenomena can occur in the discharge vicinity (3.6c). This local recirculation leads to re-entrainment of already mixed water back into the buoyant jet region. (c) In the intermediate case, a combination of localized vertical mixing and upstream spreading may result (3.6d) (CORMIX manual).

Another type of boundary interaction occurs when jets interact with the water bottom. Two types of bottom attachment can occur and are illustrated in figure 3.7. Wake attachment is created by the ambient cross flow bending the plume over causing the discharge to attach to the bottom. Coanda attachment is created by the entrainment demand of the discharge causing the jet to be pulled down to the water bottom. These bottom attachments can be avoided by proper diffuser and outfall design.

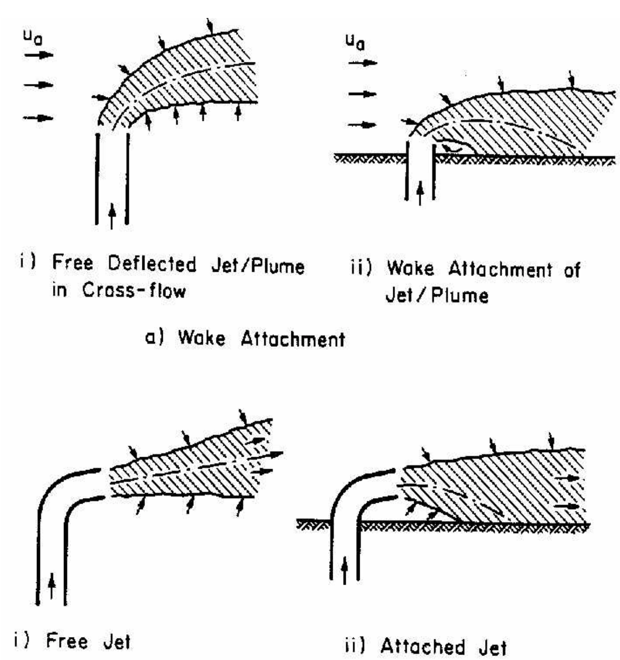

Figure 3.7: Examples of bottom attachment (CORMIX manual)

A final boundary interaction can occur somewhere within the water column at pynoclines. A pynocline is a layer where a rapid change in ambient density occurs. This often occurs in estuaries and lakes. The positively

Figure 3.8: Example of density stratification at a pynocline (Image: Hotler, ETH)

buoyant discharge hits the pynocline and stops rising because the ambient density at the pynocline is less than the discharge density. An example of this type of boundary condition is illustrated in figure 3.8.

Related to the discussion of boundary interactions is the distinction of stable or unstable near field discharges. This is a critical element of dilution analysis. The TSD clearly states the importance of considering near field stability in dilution modeling.

> *In shallow environments, it is important to determine whether near-field instabilities, associated with surface and bottom interaction and localized recirculation cells extending over the entire water depth, can cause buildup of effluent concentrations by obstructing the effluent jet flow (USEPA, 1991).*

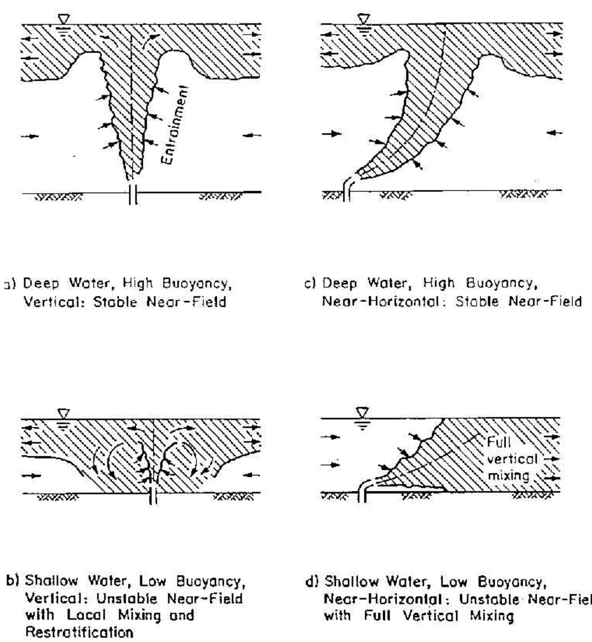

Figure 3.9: Near field stability and instability examples (CORMIX manual)

"Stable discharge" conditions, usually occurring for a combination of strong buoyancy, weak momentum and deep water, are often referred to as "deep water" conditions. "Unstable discharge" conditions, on the other hand, may be considered synonymous to "shallow water" conditions (CORMIX manual). Figures 3.9a and 3.9c illustrate near field stable conditions and figures 3.9b and 3.9d demonstrate unstable conditions in the near field. These unstable conditions usually entail re-entrainment of the fluid and boundary interaction making it difficult to use standard mixing theory and equations to predict mixing and dilution.

Far Field Processes

Two processes can occur in the far field depending on the characteristics of the discharge; 1) Buoyant ambient spreading and 2) Passive ambient diffusion. If there is a large enough density difference between the ambient and the mixed effluent buoyant spreading will occur. These spreading processes occur because of the buoyancy forces caused by the density differences between the effluent and the ambient. As a highly buoyant effluent reaches a vertical boundary (i.e. water surface) the buoyancy forces still present at the surface will cause the effluent to spread laterally and become thinner. A simple analogy is pancake batter being poured out onto a griddle. The batter thins out as it spreads laterally across the griddle. If the discharge is not buoyant or weakly buoyant, there is no buoyant spreading process occurring, only passive diffusion.

The existing turbulence in the ambient flow is the prominent cause of mixing in the passive diffusion process. Passive diffusion is characterized by diffusion and the longitudinal advection of the effluent downstream caused by the ambient velocity. Diffusion and advection are two distinct processes that occur simultaneously to affect mixing. Diffusion was first described by Adolph Fick and is famously known as Fick's Law. Fick's law states that the flux of solute mass (the mass of a solute crossing a unit area per unit time in a given direction) is proportional to the gradient of solute concentration in that direction (Fischer, 1979). For example, the concentration of a given pollutant in a discharge will flow outward toward the ambient environment due to the concentration gradient between the effluent and the ambient. This outward flux will be proportional to the concentration gradient; the larger the difference the greater the flux. In a stagnant environment (no velocity currents), a pollutant concentration will mix and become more dilute simply by the process of diffusion. An example of diffusion is a wood stove in a home. The hot air surrounding the wood stove moves toward ambient air that is cooler, because of the temperature difference, and slowly warms the air in the room.

Using the wood stove example above we can describe advection. The transport of a fluid by the mean motion of the fluid is known as advection. Advection, in the case of the wood stove example, would be caused by a fan blowing the hot air into the room. Likewise, longitudinal advection in a river is caused by the velocity of the river transporting the effluent discharge downstream. The combination of the diffusion and advection cause the effluent plume to be mixed in the far field. The mixing rate in the passive ambient diffusion process is typically much lower than mixing rates in the near field.

Entrainment

The energy created by momentum and buoyancy causes mixing of the discharge fluid with the ambient water by a process known as entrainment. Entrainment is the process of drawing ambient fluid into the jet or plume. It is a result of the momentum exchange between the jet and the ambient water. The faster moving jet causes the ambient fluid to speed up. This is caused by the viscous shear between the two fluids. Another more prominent mechanism causing the faster fluid to speed up the ambient fluid is turbulence. Small turbulent eddies at the edge of the jet or plume carry ambient water into the discharged fluid (see figure 3.1 and 3.2). Since mass must be conserved, the ambient fluid that is entrained into the plume or jet must be replaced by the discharged effluent and vice versa. Rapid mixing occurs near the discharge where the relative differences in velocity and buoyancy are high. The entrainment rate is high when the relative velocity between the jet and ambient water is high. The entrainment rate is reduced and decreases as the jet loses momentum.

An important mixing process to discuss occurs in the immediate area outside of the outfall. This is the area from the jet orifice to about six jet diameters and is termed the zone of flow establishment (ZOFE). The ZOFE is this area immediately away from the jet nozzle where the shear layer is still eating away at the constant velocity of the jet flow (see figure 3.10). No ambient water is entrained into this area. Immediately outside of the ZOFE the entrainment rate is high and turbulent mixing occurs. This is an important near field mixing process to understand for developing dose response relationships for toxic parameters or even high temperature discharges. A drifting organism could not be entrained into the ZOFE and therefore would not be introduced to 100% of the effluent. But, due to strong forces pulling in ambient fluid, a drifting organism would likely be entrained into the turbulent mixing area. This information may be used to determine whether a drifting organism would be exposed to the 1-hour average concentration that exceeds the CMC as discussed in the TSD. A rule of thumb is that the velocity perpendicular to the jet is about 1/10 of the jet velocity. For example, if the jet velocity coming out of the port is 3 m/s the entrainment velocity will be about 0.3 m/s immediately away from the port. This is also useful information when analyzing swimming velocities of fish and their ability to avoid the discharge in the near field region.

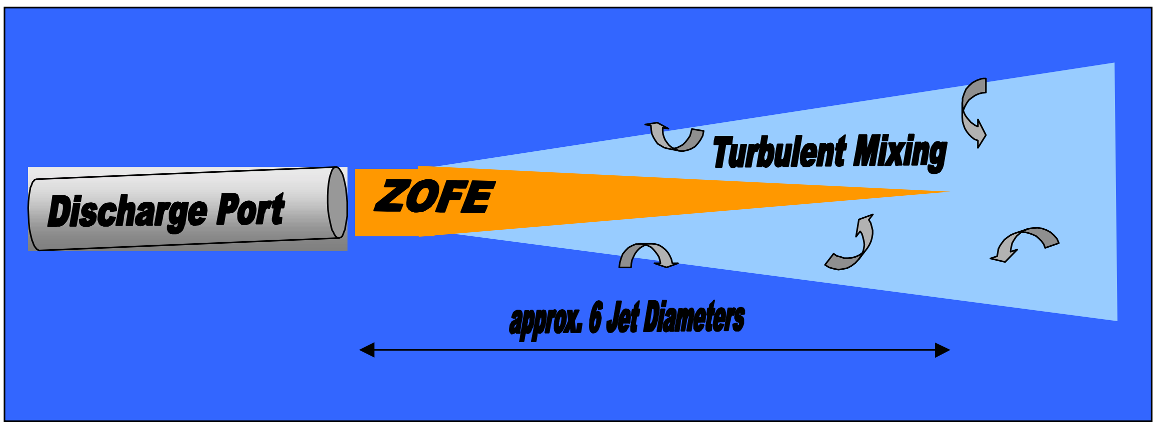

Figure 3.10: Zone of flow establishment

Chapter 4

Mixing Zone Modeling

A fundamental understanding of mixing processes and the models being used to simulate these processes is critical to performing a thorough mixing zone analysis. Simply plugging data into a model, running the model, and assuming the results reflect reality is an incorrect use and abuse of a model. Caution must be used when using these models understanding that “simulations” are being run and the output received are “predictions” of what is actually occurring. It is important to understand that mixing zone modeling is not an exact science. Results may vary from actual conditions by as much as +/- 50%.

Modeling is a science as well as an art. There is no single correct way to model a given situation. This section on modeling discusses criteria to use when deciding what model is appropriate for a given circumstance. It also provides a cursory discussion of sensitivity analysis.

It is important to note that mixing zone analysis is typically understood to apply to steady state conditions. Steady state means not changing over time. Since point source discharge mixing processes take place over the order of minutes to an hour, most outfall conditions can be assumed to be steady state. In areas of tidal influence this may not be the case and dynamic models may need to be used or several steady state model scenarios could be used.

4.1 Choosing an Appropriate Model(s)

This section will not discuss the applicability of specific models to various discharge situations. This section is intended only to discuss what parameters or characteristics of a discharge that need to be evaluated when determining what mixing zone model is most appropriate for a given situation.

A wide variety of mixing zone models exists for evaluating the mixing behavior and plume dynamics of a point source discharge. There is no single model that is appropriate for every discharge situation. Each model has its own set of strengths and weaknesses. It may be appropriate and usually encouraged to use more than one model to evaluate mixing and dilution if more than one is available to the modeler. Using an EPA recognized and supported model is typically a good choice as these have gone through internal review and scrutiny.

When determining which model(s) is appropriate, the first step should be to familiarize your self with the assumptions and limits of the various models. Davis (1999) provides a detailed description of the most widely used models and discusses their strengths and weaknesses. This may be a good place to start gaining a better understanding of the available models and their applications. It should be noted that Davis is the developer of one of the models that he reviews in his book. EPA (1994) has a good discussion of dilution modeling and two EPA supported models RSB and UM. The CORMIX manual is also a good source for mixing processes and discusses the capabilities of CORMIX. Washington Department of Ecology (1997) and Brown and Caldwell et al (1998) have brief discussions of the applicability of several mixing zone models as well. Before using any model, it is important to have an understanding of the theory behind the model and to recognize its limitations. Reading the supporting documentation for all the available models will give you a greater knowledge of mixing processes in general and a better understanding of each specific model.

The next step in deciding which model is most suitable for the discharge in question is classifying the discharge. There are three distinct discharge classifications. Not all models are able to simulate all three conditions. Determine what type of discharge you have and then choose which model(s) are applicable. The three classifications are as follows:

1. Submerged single port diffuser
2. Submerged multi-port diffuser
3. Surface discharge

Once you have classified the discharge, determining the possibility of boundary interaction is critical. You may need to run a few simulations with all applicable models to determine if there are boundary interactions in the area of interest. If there are significant boundary interactions, the appropriate model(s) that can simulate this should be selected. Some models are able to simulate the effects of boundary interactions. For models that are not capable of simulating boundary effects, some modelers use an imaging method to "force" a given model to simulate surface or bottom attachments. This method is not suggested for the novice user. When using the imaging method, specific conditions can not be violated or the method is not valid, and the user must check some of the results manually to avoid the plume entraining more water than is available in the waterbody. Remember that the simplest approach which provides adequate detail for your purposes is recommended.

Another important step in choosing an appropriate model is determining whether there are instabilities in the near field. The TSD states the following regarding instabilities:

> *In shallow environments, it is important to determine whether near-field instabilities, associated with surface and bottom interaction and localized recirculation cells extending over the entire water depth, can cause buildup of effluent concentrations by obstructing the effluent jet flow.*

Some of the models specify the type of flow class. The flow class describes the hydrodynamic characteristics of the discharge. These flow classes were developed as part of the CORMIX model. For example, these flow classes include discharges that attach to the bottom, plumes becoming trapped due to density stratification, plumes that protrude upstream due to buoyancy affects, and many others. Based on these flow classes you can determine if the near-field flow is stable or unstable. You will need a copy of the CORMIX manual for the description of the flow classes. If the model predicts an unstable flow class, CORMIX may be your most desirable choice of mixing zone models since it can predict mixing under unstable conditions. In many cases, use of other models that ignore near-field instabilities will result in over prediction of dilution in the near field region if re-entrainment of the mixed effluent with the jet or plume is occurring. Further discussions of discharge stability is beyond the scope of this document and are presented in other documentation (Jirka, 1982 and Holley, 1986).

Once you have gone through the above exercises you should be able to narrow your choice of models. If more than one model is applicable for the given discharge situation, use the model which appears to be most suitable or the one which is most familiar to you. Using an additional model to compare results against is highly recommended. As discussed above, mixing zone modeling is not an exact science and results can vary greatly between models and when compared to reality. For the non-complex discharge situations, model predictions are in agreement within about 15 – 30 %. Comparing two model predictions can give you a better sense of how well the models are predicting reality.

4.2 Sensitivity Analysis

The model input data is often based on average conditions, manipulated to fit the model input parameters, or the data is assumed. Because of the uncertainty of the input data, performing sensitivity analysis on select input parameters is critical for determining the range of results that can be expected. Sensitivity analysis also allows you to determine which parameters the model is most sensitive to. If necessary, better data for those parameters that prove to be highly sensitive could be collected to reduce the variability of the model results. For example, ambient velocity is typically a critical parameter controlling mixing. You may find the model is highly sensitive to changes in ambient velocity. If the velocity data used was based on assumptions, getting better instream velocity data may be needed to feel more comfortable about the model predictions.

Sensitivity analysis is not difficult and can actually be very interesting. The first rule of thumb for sensitivity analysis is to change only one input variable at a time. When you try changing more than one variable at a time, it is impossible to determine which input variable caused the changes in the output results. Sensitivity analysis requires performing two model runs for each parameter to be evaluated. For the first simulation, the parameter in question should be set at the lowest expected value, and the second simulation set at the highest expected value. The results of these two simulations describe how “sensitive” the model is to that particular parameter.

There are two factors that affect the variability range of a given input parameter when performing sensitivity analysis. The first is the uncertainty of the value(s) of the parameter in question. For example, the instream depth at the critical flow rate may not be known; therefore, a wide range in the depth values may need to be assumed for model input. This wide range in depth values may or may not have a large affect on the model results. This leads to the second factor. The second factor is the sensitivity of the model output to the parameter being evaluated. For example, in shallow streams model output can be highly sensitive to the stream depth in determining the amount of dilution available. The combination of these two factors, uncertainty of the input parameter and its significance on the model predictions, can create a very large uncertainty in the model results. In contrast, for a situation where the discharge is to a large, deep, waterbody, the actual depth of the discharge during critical flow may not be known. Because the waterbody is so big, the depth may not be very critical and therefore wide ranges in depth may not have a large affect on the model predictions. This is a critical point to remember particularly when gathering or collecting data. Before getting the data, determine which input variables the model is going to be most sensitive to. Make a point to obtain accurate and precise data for these variables to limit the output variability of the model.

Once the sensitivity analysis is complete you can outline the range of results and determine what conditions will be assumed for your final analysis. For the protection of water quality and beneficial uses it is always best to stay towards the conservative side unless good reason demonstrates otherwise.

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APPENDICES

Appendix A

Oregon Department of Environmental Quality Mixing Zone Rules

The mixing zone language is repeated in the Oregon Administrative Rules (OAR) Section 340-41 under each basin. The mixing zone language and all other OARs are available online at http://www.deq.state.or.us/about/rules.htm. The mixing zone language reads as follows;

(4) Mixing zones:

(a) The Department may allow a designated portion of a receiving water to serve as a zone of dilution for wastewaters and receiving waters to mix thoroughly and this zone will be defined as a mixing zone;

(b) The Department may suspend all or part of the water quality standards, or set less restrictive standards, in the defined mixing zone, provided that the following conditions are met:

(A) The water within the mixing zone shall be free of:

(i) Materials in concentrations that will cause acute toxicity to aquatic life as measured by a Department approved bioassay method. Acute toxicity is lethality to aquatic life as measured by a significant difference in lethal concentration between the control and 100 percent effluent in an acute bioassay test. Lethality in 100 percent effluent may be allowed due to ammonia and chlorine only when it is demonstrated on a case-by-case basis that immediate dilution of the effluent within the mixing zone reduces toxicity below lethal concentrations. The Department may on a case-by-case basis establish a zone of immediate dilution if appropriate for other parameters;

(ii) Materials that will settle to form objectionable deposits;

(iii) Floating debris, oil, scum, or other materials that cause nuisance conditions;

(iv) Substances in concentrations that produce deleterious amounts of fungal or bacterial growths.

(B) The water outside the boundary of the mixing zone shall:

(i) Be free of materials in concentrations that will cause chronic (sublethal) toxicity. Chronic toxicity is measured as the concentration that causes long-term sublethal effects, such as significantly impaired growth or reproduction in aquatic organisms, during a testing period based on test species life cycle. Procedures and end points will be specified by the Department in wastewater discharge permits;

(ii) Meet all other water quality standards under normal annual low flow conditions.

(c) The limits of the mixing zone shall be described in the wastewater discharge permit. In determining the location, surface area, and volume of a mixing zone area, the Department may use appropriate mixing zone guidelines to assess the biological, physical, and chemical character of receiving waters, and effluent, and the most appropriate placement of the outfall, to protect instream water quality, public health, and other beneficial uses. Based on receiving water and effluent characteristics, the Department shall define a mixing zone in the immediate area of a wastewater discharge to:

(A) Be as small as feasible;

(B) Avoid overlap with any other mixing zones to the extent possible and be less than the total stream width as necessary to allow passage of fish and other aquatic organisms;

(C) Minimize adverse effects on the indigenous biological community especially when species are present that warrant special protection for their economic importance, tribal significance, ecological uniqueness, or for other similar reasons as determined by the Department and does not block the free passage of aquatic life;

(D) Not threaten public health;

(E) Minimize adverse effects on other designated beneficial uses outside the mixing zone.

(d) The Department may request the applicant of a permitted discharge for which a mixing zone is required, to submit all information necessary to define a mixing zone, such as:

(A) Type of operation to be conducted;

(B) Characteristics of effluent flow rates and composition;

(C) Characteristics of low flows of receiving waters;

(D) Description of potential environmental effects;

(E) Proposed design for outfall structures.

(e) The Department may, as necessary, require mixing zone monitoring studies and/or bioassays to be conducted to evaluate water quality or biological status within and outside the mixing zone boundary;

(f) The Department may change mixing zone limits or require the relocation of an outfall if it determines that the water quality within the mixing zone adversely affects any existing beneficial uses in the receiving waters.

(g) Alternate requirements for mixing zones: For some existing or proposed discharges to some receiving streams, it may not be practicable to treat wastewater to meet instream water quality standards at the point of discharge or within a short distance from the point of discharge. Some of these discharges could be allowed without impairing the overall ecological integrity of the receiving streams, or may provide an overall benefit to the receiving stream. This section specifies the conditions and circumstances under which a mixing zone may be allowed by the Department that extends beyond the immediate area around a discharge point, or that extends across a stream width. An alternate mixing zone may be approved if the applicant demonstrates to the Department's satisfaction that the discharge (A) creates an overall environmental benefit, or (B) is to a constructed water course, or (C) is insignificant. The three circumstances under which alternate mixing zones may be established are described further below.

(A) Overall environmental benefit.

(i) Qualifying for alternate mixing zone based on overall environmental benefit: In order to qualify for an alternate mixing zone based on a finding of overall environmental benefit, the discharger must demonstrate to the Department's satisfaction the following:

(I) That all practical strategies have been or will be implemented to minimize the pollutant loads in the effluent; and

(II) For proposed increased discharges, the current actual discharge and mixing zone does not meet the requirements of a standard mixing zone; and

(III) Either that, on balance, an environmental benefit would be lost if the discharge did not occur, or that the discharger is prepared to undertake other actions that will mitigate the effect of the discharge to an extent resulting in a net environmental benefit to the receiving stream.

(IV) For the purposes of this rule, the term "practical" shall include environmental impact, availability of alternatives, cost of alternatives, and other relevant factors.

(ii) Studies required and evaluation of studies: In order to demonstrate that, on balance, an environmental benefit will result from the discharge, the following information shall be provided by the applicant:

(I) The effluent flow and pollutant loads that are detected or expected in the effluent, by month, both average and expected worst case discharges. The parameters to be evaluated include at a minimum temperature, biochemical oxygen demand, total suspended solids, total dissolved solids, pH, settleable solids, e. coli bacteria, oil and grease, any pollutants listed in Table 20 of this rule division, and any pollutant for which the receiving stream has been designated by the Department as water quality limited; and

(II) Receiving stream flow, by month; and

(III) The expected impact of the discharge, by month, on the receiving stream for the entire proposed mixing zone area for all of the pollutants listed above. Included in this analysis shall be a comparison of the receiving stream water quality with the discharge and without the discharge; and

(IV) A description of fish, other vertebrate populations, and macroinvertebrates that reside in or are likely to pass through the proposed mixing zone, including expected location (if known), species identification, stage of development, and time of year when their presence is expected. For existing discharges, the applicant shall provide the same information for similar nearby streams that are unaffected by wastewater discharges. In addition, any threatened or endangered species in the immediate vicinity of the receiving stream shall be identified; and

(V) The expected impact of the discharge on aquatic organisms and/or fish passage, including any expected negative impacts from the effluent attracting fish where that is not desirable; and

(VI) A description of the expected environmental benefits to be derived from the discharge or other mitigation measures proposed by the applicant, including but not limited to improvements in water quality, improvements in fish passage, and improvements in aquatic habitat. If the applicant proposes to undertake mitigation measures designed to provide environmental benefits (e.g., purchasing water or water conservation rights to increase stream flows or establishing stream cover to decrease temperature), the applicant shall describe the mitigation measures in detail, including a description of the steps it will take to ensure that the benefits of the mitigation measures are attained and are not lost or diminished over time.

(VII) Some or all of the above study requirements may be waived by the Department, if the Department determines that the information is not needed. In the event that the Department does waive some or all of the above study requirements, the basis for waiving the requirements will be included in the permit evaluation report upon the next permit renewal or modification relating to the mixing zone.

(VIII) Upon request of the Department, the applicant shall conduct additional studies to further evaluate the impact of the discharge, which may include whole effluent toxicity testing, stream surveys for water quality, stream surveys for fish and other aquatic organisms, or other studies as specified by the Department.

(IX) In evaluating whether an existing or proposed increase in an existing discharge would result in a net environmental benefit, the applicant shall use the native biological community in a nearby, similar stream that is unaffected by wastewater discharges. The

Department shall consider all information generated as required in this rule and other relevant information. The evaluation shall consider benefits to the native aquatic biological community only.

(iii) Permit conditions: Upon determination by the Department that the discharge and mitigation measures (if any) will likely result in an overall environmental benefit, the Department shall include appropriate permit conditions to insure that the environmental benefits are attained and continue. Such permit conditions may include but not be limited to:

(I) Maximum allowed effluent flows and pollutant loads;

(II) Requirements to maintain land ownership, easements, contracts, or other legally binding measures necessary to assure that mitigation measures, if any, remain in place and effective;

(III) Special operating conditions;

(IV) Monitoring and reporting requirements; and

(V) Studies to evaluate the effectiveness of mitigation measures.

(B) Constructed water course: A mixing zone may be extended through a constructed water course and into a natural water course. For the purposes of this rule, a constructed water course is one that was constructed for irrigation, site drainage, or wastewater conveyance, and has the following characteristics:

(i) Irrigation flows, stormwater runoff, or wastewater flows have replaced natural streamflow regimes; and

(ii) The channel form is greatly simplified in lengthwise and cross sectional profiles; and

(iii) Physical and biological characteristics that differ significantly from nearby natural streams; and

(iv) A much lower diversity of aquatic species than found in nearby natural streams; and

(v) If the constructed water course is an irrigation canal, then it must have effective fish screens in place to qualify as a constructed water course.

(C) Insignificant discharges: Insignificant discharges are those that either by volume, pollutant characteristics, and/or temporary nature are expected to have little if any impact on beneficial uses in the receiving stream, and for which the extensive evaluations required for discharges to smaller streams are not warranted. For the purposes of this rule, only filter backwash discharges and underground storage tank cleanups are considered insignificant discharges.

(D) Other requirements for alternate mixing zones: The following are additional requirements for dischargers requesting an alternate mixing zone:

(i) Most discharges that qualify for an alternate mixing zone will extend through the receiving stream until a larger stream is reached, where thorough mixing of the effluent can occur and where the edge of the allowed mixing zone will be located. The portion of the mixing zone in the larger stream must meet all of the requirements of the standard mixing zone, including not blocking aquatic life passage; and

(ii) An alternate mixing zone shall not be granted if a municipal drinking water intake is located within the proposed mixing zone, and the discharge has a significant adverse impact on the drinking water source; and

(iii) The discharge will not pose an unreasonable hazard to the environment or pose a significant health risk, considering the likely pathways of exposure; and

(iv) The discharge shall not be acutely toxic to organisms passing through the mixing zone; and

(v) An alternate mixing zone shall not be granted if the substances discharged may accumulate in the sediments or bioaccumulate in aquatic life or wildlife to levels that adversely affect public health, safety, or welfare; aquatic life; wildlife; or other designated beneficial uses; and

(vi) In the event that the receiving stream is water quality limited, the requirements for discharges to water quality limited streams supersede this rule.

(5) Testing methods: The analytical testing methods for determining compliance with the water quality standards contained in this rule shall be in accordance with the most recent edition of Standard Methods for the Examination of Water and Waste Water published jointly by the American Public Health Association, American Water Works Association, and Water Pollution Control Federation, unless the Department has published an applicable superseding method, in which case testing shall be in accordance with the superseding method; provided, however, that testing in accordance with an alternative method shall comply with this rule if the Department has published the method or has approved the method in writing.

[ED. NOTE: The Table(s) referenced in this rule is not printed in the OAR Compilation. Copies are available from the agency.]

[Publications: The publication(s) referred to or incorporated by reference in this rule are available from the office of the agency.]

Stat. Auth.: ORS 468.735, ORS 468B.035 & ORS 468B.048

Stats. Implemented: ORS 468B.048

Hist.: DEQ 128, f. & ef. 1-21-77; DEQ 1-1980, f. & ef. 1-9-80; DEQ 18-1987, f. & ef. 9-4-87; DEQ 14-1991, f. & cert. ef. 8-13-91; DEQ 17-1992, f. & cert. ef. 8-7-92 (and corrected 8-13-92); DEQ 6-1995, f. & cert. ef. 2-28-95; DEQ 21-1995(Temp), f. & cert. ef. 9-21-95; DEQ 5-1995, f. & cert. ef. 3-7-96; DEQ 22-1997, f. & cert. ef. 10-24-97

Appendix B

Reasonable Potential Analysis

The federal rules make it clear that a dischargers effluent must be characterized and an analysis needs to be performed to determine whether the discharge causes, has the reasonable potential to cause, or contributes to an excursion of water quality criteria. This reasonable potential analysis is described in detail in chapter 3, section 3.3.2 of the TSD. Box 3-2 of the TSD lays out a step-by-step process that is summarized below. The TSD should be read for further detail.

EPA recommends finding that a permittee has "reasonable potential" to exceed a reciving water quality standard if it cannot be demonstrated with a high confidence level that the upper bound of the lognormal distribution of effluent concentrations is below the receiving water criteria at specified critical flow conditions.

Step 1 Determine the number of total observations (n) for a particular set of effluent data and determine the highest value from that data set.

Step 2 Determine the coefficient of variation (CV) for the data set. For a data set where n<10, assume a coefficient of 0.6. For a data set where n>10, the CV is calculated as the standard deviation/mean.

Step 3 Determine the appropriate ratio from Table 3-1 or 3-2 (in TSD).

Step 4 Multiply the highest value from a data set by the value from step 3. Use this value with the appropriate dilution to project a maximum receiving water concentration (RWC).

Step 5 Compare the projected maximum RWC to the applicable standard (acute or chronic criterion). EPA recommends that permitting authorities find reasonable potential when the projected RWC is greater than an ambient criterion.

Example

Consider the following chlorine results measured from the effluent from municipal wastewater treatment plant: number of observations (n) = 20, maximum value = 0.5 mg/L, mean = 0.3 mg/L, standard deviation 0.12. Assume the effluent is diluted to 2 percent at the edge of the mixing zone. Further assume the upper bound of the effluent distribution is the 99th percentile, and the confidence level is 99 percent.

Step 1 There are a total of 20 observations and the maximum value is 0.5 mg/L.

Step 2 The coefficient of variation equals the standard deviation/mean = 0.12/0.3 = 0.4.

Step 3 The value of the ratio for 20 observations and a CV of 0.4 (from Table 3-1, TSD) is 1.8.

Step 4 The value that exceeds the 99th percentile of the distribution is equal to the maximum value multiplied by the value from step 3: 0.5 x 1.8 = 0.9 mg/L.

The concentration at the edge of the mixing zone is calculated to be 0.02 x 0.9 = .018 mg/L.

Step 5 The chronic criterion for chlorine is 0.011 mg/L. Therefore there is reasonable potential for this effluent to cause an excursion above the chronic criterion concentration.

Below is an example table from the Department's reasonable potential spreadsheet. This spreadsheet is available from the nearest regional office.

Table B.1 : Reasonable potential ouput table

Reasonable Potential Analysis Facility Name = **Big City WWTP** (data is based on 1998-1999 DMRs)

CORMIX OUTPUT?	Y (Y/N)	
Dilution @ ZID =	14 (**S**)	
Dilution @ MZ =	56 (**S**)	
Facility Effluent Flow=	13	MGD
Confidence Level =	99	%
Probability Basis =	99	%

RECEIVING WATER INFORMATION:		
Hardness =	55	mg/l
7Q10 =	*	CFS
1Q10 =	*	CFS
% dilution at ZID =	*	%
% dilution at MX =	*	%

PARAMETER	# of Samples	Highest Conc. µg/l	Coef. of Varience	Maximum Effluent Conc. µg/l	Background Conc. µg/l	Maximum Conc. at ZID µg/l	Maximum Conc. at MZ µg/l	WATER QUALITY CRITERIA 1 Hour (CMC) µg/l	WATER QUALITY CRITERIA 4 Day (CCC) µg/l	REASONABLE POTENTIAL ? ACUTE	REASONABLE POTENTIAL ? CHRONIC
ALUMINUM †	5	1.00	0.60	4.20	0.00	0.30	0.08	750.00	87.00	**no**	**no**
ARSENIC V	5	3.10	0.60	13.02	0.00	0.93	0.23	850.00	48.00	**no**	**no**
ARSENIC III	5	10.00	0.60	42.00	0.00	3.00	0.75	360.00	190.00	**no**	**no**
CADMIUM *	55	64.00	1.20	153.60	0.05	11.02	2.79	2.00	0.71	**YES**	**YES**
CHROMIUM VI	5	33.00	0.60	138.60	0.02	9.91	2.49	16.00	11.00	**no**	**no**
CHROMIUM III *	5	10.00	0.60	42.00	0.00	3.00	0.75	1064.23	126.85	**no**	**no**
TOTAL CHROMIUM * †	35	33.00	2.00	145.20	0.02	10.39	2.61	1080.23	137.85	**no**	**no**
COPPER *	35	36.00	2.00	158.40	0.01	11.32	2.84	10.09	7.09	**YES**	**no**
CYANIDE	35	100.00	1.40	340.00	0.00	24.29	6.07	22.00	5.20	**YES**	**YES**
FLUORIDE †	35	880.00	2.00	3872.00	0.20	276.76	69.34	2000.00	1000.00	**no**	**no**
IRON ‡	35	940.00	2.00	4136.00	0.10	295.52	73.96	2000.00	1000.00	**no**	**no**
LEAD *	55	210.00	1.10	483.00	0.75	35.20	9.36	38.76	1.51	**no**	**YES**
MERCURY	55	11.00	3.30	47.30	0.006	3.38	0.85	2.40	0.012	**YES**	**YES**
NICKEL *	35	93.00	2.00	409.20	0.02	29.25	7.33	856.63	95.08	**no**	**no**
SILVER *	54	10.00	1.30	25.00	0.06	1.84	0.51	1.45	0.12	**YES**	**YES**
ZINC *	5	78.00	0.37	195.00	0.03	13.96	3.51	70.51	63.87	**no**	**no**

NOTES :

If CORMIX data (S) is available, the flow data and % dilution is not necessary.

* - Hardness Dependant

† - Not DEQ Criteria

‡ - No acute standard. The CMC is estimated as 2X the CCC.

Table 3-1. Reasonable Potential Multiplying Factors: 99% Confidence Level and 99% Probability Basis

Number of	Coefficient of Variation																			
Samples	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
1	1.6	2.5	3.9	6.0	9.0	13.2	18.9	26.5	36.2	48.3	63.3	81.4	102.8	128.0	157.1	190.3	227.8	269.9	316.7	368.3
2	1.4	2.0	2.9	4.0	5.5	7.4	9.8	12.7	16.1	20.2	24.9	30.3	36.3	43.0	50.4	58.4	67.2	76.6	86.7	97.5
3	1.4	1.9	2.5	3.3	4.4	5.6	7.2	8.9	11.0	13.4	16.0	19.0	22.2	25.7	29.4	33.5	37.7	42.3	47.0	52.0
4	1.3	1.7	2.3	2.9	3.8	4.7	5.9	7.2	8.7	10.3	12.2	14.2	16.3	18.6	21.0	23.6	26.3	29.1	32.1	35.1
5	1.3	1.7	2.1	2.7	3.4	4.2	5.1	6.2	7.3	8.6	10.0	11.5	13.1	14.8	16.6	18.4	20.4	22.4	24.5	26.6
6	1.3	1.6	2.0	2.5	3.1	3.8	4.6	5.5	6.4	7.5	8.6	9.8	11.1	12.4	13.8	15.3	16.8	18.3	19.9	21.5
7	1.3	1.6	2.0	2.4	2.9	3.6	4.2	5.0	5.8	6.7	7.7	8.7	9.7	10.8	12.0	13.1	14.4	15.6	16.9	18.2
8	1.2	1.5	1.9	2.3	2.8	3.3	3.9	4.6	5.3	6.1	6.9	7.8	8.7	9.6	10.6	11.6	12.6	13.6	14.7	15.8
9	1.2	1.5	1.8	2.2	2.7	3.2	3.7	4.3	5.0	5.7	6.4	7.1	7.9	8.7	9.6	10.4	11.3	12.2	13.1	14.0
10	1.2	1.5	1.8	2.2	2.6	3.0	3.5	4.1	4.7	5.3	5.9	6.6	7.3	8.0	8.8	9.5	10.3	11.0	11.8	12.6
11	1.2	1.5	1.8	2.1	2.5	2.9	3.4	3.9	4.4	5.0	5.6	6.2	6.8	7.4	8.1	8.8	9.4	10.1	10.8	11.5
12	1.2	1.4	1.7	2.0	2.4	2.8	3.2	3.7	4.2	4.7	5.2	5.8	6.4	7.0	7.5	8.1	8.8	9.4	10.0	10.6
13	1.2	1.4	1.7	2.0	2.3	2.7	3.1	3.6	4.0	4.5	5.0	5.5	6.0	6.5	7.1	7.6	8.2	8.7	9.3	9.9
14	1.2	1.4	1.7	2.0	2.3	2.6	3.0	3.4	3.9	4.3	4.8	5.2	5.7	6.2	6.7	7.2	7.7	8.2	8.7	9.2
15	1.2	1.4	1.6	1.9	2.2	2.6	2.9	3.3	3.7	4.1	4.6	5.0	5.4	5.9	6.4	6.8	7.3	7.7	8.2	8.7
16	1.2	1.4	1.6	1.9	2.2	2.5	2.9	3.2	3.6	4.0	4.4	4.8	5.2	5.6	6.1	6.5	6.9	7.3	7.8	8.2
17	1.2	1.4	1.6	1.9	2.1	2.5	2.8	3.1	3.5	3.8	4.2	4.6	5.0	5.4	5.8	6.2	6.6	7.0	7.4	7.8
18	1.2	1.4	1.6	1.8	2.1	2.4	2.7	3.0	3.4	3.7	4.1	4.4	4.8	5.2	5.6	5.9	6.3	6.7	7.0	7.4
19	1.2	1.4	1.6	1.8	2.1	2.4	2.7	3.0	3.3	3.6	4.0	4.3	4.6	5.0	5.3	5.7	6.0	6.4	6.7	7.1
20	1.2	1.3	1.6	1.8	2.0	2.3	2.6	2.9	3.2	3.5	3.8	4.2	4.5	4.8	5.2	5.5	5.8	6.1	6.5	6.8

Table 3-2. Reasonable Potential Multiplying Factors: 95% Confidence Level and 95% Probability Basis

Number of	Coefficient of Variation																			
Samples	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
1	1.4	1.9	2.6	3.6	4.7	6.2	8.0	10.1	12.6	15.5	18.7	22.3	26.4	30.8	35.6	40.7	46.2	52.1	58.4	64.9
2	1.3	1.6	2.0	2.5	3.1	3.8	4.6	5.4	6.4	7.4	8.5	9.7	10.9	12.2	13.6	15.0	16.4	17.9	19.5	21.1
3	1.2	1.5	1.8	2.1	2.5	3.0	3.5	4.0	4.6	5.2	5.8	6.5	7.2	7.9	8.6	9.3	10.0	10.8	11.5	12.3
4	1.2	1.4	1.7	1.9	2.2	2.6	2.9	3.3	3.7	4.2	4.6	5.0	5.5	6.0	6.4	6.9	7.4	7.8	8.3	8.8
5	1.2	1.4	1.6	1.8	2.1	2.3	2.6	2.9	3.2	3.6	3.9	4.2	4.5	4.9	5.2	5.6	5.9	6.2	6.6	6.9
6	1.1	1.3	1.5	1.7	1.9	2.1	2.4	2.6	2.9	3.1	3.4	3.7	3.9	4.2	4.5	4.7	5.0	5.2	5.5	5.7
7	1.1	1.3	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.9
8	1.1	1.3	1.4	1.6	1.7	1.9	2.1	2.3	2.4	2.6	2.8	3.0	3.2	3.3	3.5	3.7	3.9	4.0	4.2	4.3
9	1.1	1.2	1.4	1.5	1.7	1.8	2.0	2.1	2.3	2.4	2.6	2.8	2.9	3.1	3.2	3.4	3.5	3.6	3.8	3.9
10	1.1	1.2	1.3	1.5	1.6	1.7	1.9	2.0	2.2	2.3	2.4	2.6	2.7	2.8	3.0	3.1	3.2	3.3	3.4	3.6
11	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.1	2.2	2.3	2.4	2.5	2.7	2.8	2.9	3.0	3.1	3.2	3.3
12	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.0
13	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.5	2.6	2.7	2.8	2.9
14	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.3	2.4	2.5	2.6	2.6	2.7
15	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2.0	2.1	2.2	2.2	2.3	2.4	2.4	2.5	2.5
16	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.3	2.3	2.4	2.4
17	1.1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2.0	2.0	2.1	2.2	2.2	2.3	2.3
18	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.7	1.8	1.9	1.9	2.0	2.0	2.1	2.1	2.2	2.2
19	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.6	1.7	1.8	1.8	1.9	1.9	2.0	2.0	2.0	2.1	2.1
20	1.1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.8	1.8	1.9	1.9	2.0	2.0	2.0

Appendix C

Dilution

One of the most important products of a mixing zone analysis is the derivation of dilution. Dilution is a critical component of water quality based permitting. It is the driving variable in reasonable potential analysis and water quality-based permit limit derivation. Without dilution results, there is no way of determining compliance with water quality standards outside of an assigned mixing zone.

Dilution values typically need to be known for two mixing zones and often times a third mixing zone as well. The most common mixing zones are the acute mixing zone (usually referred as the **zone of initial dilution**) and the chronic mixing zone (usually referred to as **the mixing zone**). The third mixing zone that is often times important, depending on the characteristics of the effluent, is the human health mixing zone. The human health mixing zone is often times overlooked and not incorporated into permitting analysis or criteria for human health are applied at the edge of the chronic mixing zone. Because human health criteria are based on long-term exposure (over a lifetime), the mixing zone for human health can be based on complete mix with the receiving water body.

In mixing analysis and mixing zone modeling volumetric dilution is typically defined as:

$$S = \frac{Va + Ve}{Ve} = \frac{Va}{Ve} + 1 \qquad (2.1)$$

where
S = dilution
Ve = volume of effluent
Va = volume of ambient

For undiluted effluent S = 1, and for pure ambient water S = ∞. Another definition for dilution that is often times used is simply the volume of the ambient divided by the volume of the effluent (S = Va/Ve). In this case the dilution for an undiluted effluent is zero. The difference between the values of the two dilution definitions is 1 as seen in equation 2.1. Regardless of the small difference between the values it is important to be specific about the definition of dilution being used.

The first definition is preferred because it is derived from the continuity equation. The continuity equation is used to calculate the concentration of a contaminant in the mixed effluent and is defined as follows:

$$CmVm = CeVe + CaVa \qquad (2.2)$$

where

Cm = average pollutant concentration in the mixed effluent
Vm = volume of mixed effluent (Va+Ve)
Ce = pollutant concentration of the effluent
Ve = volume of the effluent
Ca = pollutant concentration of the ambient water (background)
Va = volume of the ambient water

In the case where the concentration of the ambient water is zero the equation becomes

$$CmVm = CeVe \tag{2.3}$$

Rearranging the equation and substituting Ve+Va for Vm

$$\frac{Ce}{Cm} = \frac{Va + Ve}{Ve} \tag{2.4}$$

In the absence of a pollutant in the background receiving water the volumetric dilution (S) is equal to the dilution of a pollutant (Ce/Cm). For this reason, hydrodynamic models use this definition for dilution.

In the case where the background pollutant concentration is not zero, equation 2.2 can be rearranged so that

$$S = \frac{Ce - Ca}{Cm - Ca} \tag{2.5}$$

$$Cm = Ca + \frac{1}{S}(Ce - Ca) \tag{2.6}$$

Dilution values obtained from model predictions should be plugged into equation 2.6 along with the effluent and background concentrations to calculate the pollutant concentration at a given point downstream.

It is important to have an understanding of the difference between centerline and average dilutions (and plume concentrations) in relation to hydrodynamic models. Depending on the model used the dilution results may be given as centerline or average dilutions. The modeling documentation should be consulted to determine whether the dilution results are centerline or average values. Centerline dilution is less than the plume average and be the more conservative value for regulatory purposes. Some of the model documentation will also describe the relationship between centerline and average dilution so that one can be calculated if the other is given as the output. For example, the dilution given by CORMIX for submerged jet or plume regions is the centerline dilution. If the average dilution is desired, the ratio of average dilution to centerline dilution is 1.7. If the predicted centerline dilution is 50, the average dilution would be 85 (50 x 1.7).

Appendix D

Glossary

Advection – the transport of a fluid by the mean motion of the fluid.

Allocated Impact Zone (AIZ) – the point where water quality characteristics permit long-term exposure without interfering with any activity of aquatic organisms or causing ill effects to any life history state – also known as a mixing zone.

Buoyant Ambient Spreading Processes – far field mixing processes which arise due to the buoyant forces caused by the density difference between the mixed effluent and the ambient receiving water.

Buoyant Jet – a discharge where turbulent mixing is caused by a combination of initial momentum flux and buoyancy flux.

Buoyancy Flux – the submerged weight of a fluid passing through a cross-section per unit time.

Criterion Continuous Concentration – the EPA national water quality criteria recommendation for the highest instream concentration of a toxicant or an effluent to which organisms can be exposed indefinitely without causing unacceptable effect. In practice this is often the same value or is treated as a water quality standard.

Criterion Maximum Concentration – the EPA national water quality criteria recommendation for the highest instream concentration of a toxicant or an effluent to which organisms can be exposed for a brief period of time without causing an acute effect. This is usually defined as the LC_{50} concentration.

Coanda Attachment – a dynamic interaction between the effluent plume and the water bottom that results from the entrainment demand of the effluent jet itself and is due to low pressure effects.

Entrainment – the process of drawing ambient fluid into the jet or plume created by momentum and/or buoyancy forces.

Far field – the region of the receiving water where buoyant spreading motions and passive diffusion control the trajectory and dilution of the effluent discharge plume.

Jet – a discharge where only the initial momentum flux in the form of a high velocity injection causes turbulent mixing.

Harmonic mean flow – the long term mean flow used in the mixing analysis of carcinogenic pollutants for the protection of human health. It is calculated by dividing the number of daily flows analyzed by the sum of the reciprocals of those daily flows.

Manning's n – a measure of the roughness characteristics of a channel bottom.

Mass flux – the mass of fluid passing a jet cross-section per unit time.

Momentum flux – the amount of streamwise momentum passing a jet cross-section per unit time.

Mixing Zone – a regulatory boundary defining a limited area or volume where discharged effluent is allowed to mix with the receiving waterbody – also referred to as the chronic mixing zone (see figure 1.1).

Neap Tide – a tide of lowest range.

Near Field – the region of a receiving water where the initial jet characteristic of momentum flux, buoyancy flux and outfall geometry influence the jet trajectory and mixing of an effluent discharge.

Near-field Stability - determined by the amount of local recirculation and re-entrainment of already mixed water back into the buoyant jet region. Stable discharge conditions are associated with weak momentum and deep water and are also sometimes called deep water conditions. Unstable discharge conditions have localized recirculation patterns and are also called shallow water conditions.

Passive Ambient Diffusion Processes – far field mixing processes which arise due to existing turbulence in the ambient receiving water flow.

Plume – a discharge where only the initial buoyancy flux leads to local vertical accelerations which then lead to turbulent mixing.

Pynocline – a horizontal layer in the receiving waterbody where a rapid density change occurs.

Spring tide – a tide of maximum range.

Stable Discharge - see near field stability.

Technical Support Document (TSD) – EPA guidance document developed to assist states develop water quality based effluent limits for toxic pollutants from point source discharges.

Unstable Discharge - see near field stability.

Wake Attachment – a dynamic interaction of the effluent plume with the bottom that is forced by the receiving water crossflow.

Zone of Flow Establishment (ZOFE) – the area immediately away from the jet nozzle where the shear layer is still eating away at the constant velocity of the jet flow.

Zone of Initial Dilution (ZID) – an area immediately surrounding the outfall where the acute and chronic criteria can be exceeded – also referred to as the acute mixing zone (see figure 1.1).

1Q10 – the lowest one day flow with an average recurrence frequency of once in ten years.

7Q10 – the lowest seven day flow with an average recurrence frequency of once in ten years.

30Q5 - the lowest average 30 consecutive day low flow with an average recurrence frequency of once in ten years.